ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

STRUCTURAL ANALYSIS OF 9100 DWT MULTI PURPOSE SHIP

M.Sc. THESIS

Barış DEDETAŞ

Department of Naval Architecture and Naval Machinery Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

9100 DWT LİK ÇOK AMACLI GEMİNİN YAPISAL ANALİZİ

YÜKSEK LİSANS TEZİ

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Gemi İnşaatı ve Gemi Makinaları Mühendisliği Ana Bilim Dalı

Gemi İnşaatı ve Gemi Makinaları Mühendisliği Programı

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Barış DEDETAŞ, a **Mr.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID **508051016**, successfully defended the **thesis** entitled **“STRUCTURAL ANALYSIS OF 9100 DWT MULTI PURPOSE SHIP”**, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

I would like to thank, Prof. Dr. Ahmet Ergin who ensure me a free working circumstance, and also my family for everything.

OCTOBER 2009

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(Junior Engineer)

TABLE OF CONTENTS

Page

ABBREVIATIONS

BV	: Bureau VERITAS Classification Society, French
FEM	: Finite Element Method
DWT	: Deadweight of the ship
p_s	: Hydrostatic sea pressure.
g	: Gravitational acceleration.
ρ	: Density of sea water.
T	: Drought of ship
L	: Length of ship
B	: Bred of ship
C_B	: Block coefficient.
C_W	: Water plane coefficient.
a_B	: Motion and acceleration parameter.
h_W	: Wave parameter.
C	: Wave parameter.
H	: Wave parameter.
$M_{SWM,H}$	: Design still water bending moment in hogging condition.
$M_{SWM,S}$	: Design still water bending moment in sagging condition.
$M_{WV,H}$	: Vertical wave bending moment in hogging condition.
$M_{WV,S}$	: Vertical wave bending moment in sagging condition.
n_1	: Navigation coefficient.
C_M	: Wave torque coefficient.
C_Q	: Horizontal wave shear force coefficient.
Q_{WV}	: Vertical shear force.
F_M	: Distribution factor.
F_Q	: Distribution factor.
F_{TM}	: Distribution factor.
F_{TQ}	: Distribution factor.
α_H	: Heave acceleration.
α_R	: Roll acceleration.
α_P	: Pitch acceleration.
α_Y	: Yaw acceleration.
T_{SW}	: Sway period.
T_R	: Roll period.
T_P	: Pitch period.

A_R : Roll amplitude.

A_P : Pitch amplitude

LIST OF TABLES

LIST OF FIGURES

STRUCTURAL ANALYSIS OF 9100 DWT MULTI PURPOSE SHIP

SUMMARY

Nowadays, with the help of rapid improvements in technology, more complex and much bigger scale problems are become solvable with respect to past. As a good example, optimum design of ship structures, which is a very though problem, can be solved with applying numerical method especially finite element method with the help of computer technology.

The ship has been designed, depending on class society's rules. These rules depend on the class societies experiences. Finite element method as a direct strength assessment is becoming a scantling method in the rule book, but it will take time to use these methods effectively, and efficiently.

In today's rules FEM analysis procedure of the ships, which are 170m in length, is described and these are almost enough for every kind of analysis, but same thing is not valid for ships, which are less than 170m in length.

Main aim of this work is to offer a FEM analysis procedure for small, which are less than 170m in length ships by means of strength, and analyzing the 9100 DWT multi purpose ship with conventional finite element package program.

The ship, which we analyzed, has large deck opening with two cargo hold and its length is less than 170m. Therefore, we can not use the direct strength assessment method based on three cargo hold model. Because of the ship has large deck openings, it is expected that the maximum deflection of the hatchway coamings ocuures at the middle of the hatch. In one cargo hold model, the ships are modelled from the middle of the one cargo hold to the middle of the adjacent cargo hold, including the bulkhead. The boundary conditions are applied to the end of the model as well. Applying boundary condition to the place where the maximum displacement occurs is not right way for this kind of analysis. For this reason a new procedure was developed.

In this work, I tried to carry out structural analyses of a 9100 DWT multi purpose ship with conventional finite element package program. When analyzing this ship, a direct calculation method, which has originally developed by the classification societies, has been used with some modification in modelling a boundary condition, and result has been presented.

9100 DWT LİK ÇOK AMACLI GEMİNİN YAPISAL ANALİZİ

ÖZET

Günümüzde bilgisayar ve yazılım sektöründeki hızlı ilerlemeler sayesinde büyük boyutlu ve karmaşık yapılı problemlerin çözümleri de kolaylaşmaktadır. Buna güzel bir örnek ta gemi imalatının, boyutlandırma ve dizayn aşamalarında, sonlu elemanlar yöntemi ile yapılan analizlerdir.

Sonlu elemanlar yöntemi yardımıyla yapılan analizler sanayinin diğer alanlarında daha yaygın olarak kullanılırken, gemi inşa sanayisinde kullanımı pek yaygın değildir. Bunun en önemli nedeni gemi inşam sanayinin ülkemizde ve dünyada geleneksel "tecrübeye dayalı" yöntemler üzerine kurulu olması ve de bu sanayinin ana unsuru olan Sınıflandırma "Klas" kuruluşlarının ataletidir.

Günümüzde, halihazırda inşa edilen gemiler bir klas kuruluşunun kurallarına bağlı kalarak inşam edilmektedir ve bu kurallar sınıflandırma kuruluşlarının "çoğu yüz yılı aşan" tecrübe ve birikimlerinin bir sonucudur. Sonlu elemanlar yönteminin kullanımı direk hesap yöntemi adı altında, sınıflandırma kuruluşlarının kuralları arasında yerini alsa da, bu kuralların işlerlik kazanması ve prosedürlerin gelişmesi zaman alacaktır.

Halihazırda 170m ve üzeri boylarda sonlu elemanlar yöntemiyle analiz prosedürü tanımlanmış iken, boyu 170m'nin altında olan gemiler için olan analiz prosedürü yetersiz kalmaktadır.

Bu çalışmada temel amacımız, gemi boyutlandırmasında sonlu elemanlar kullanımına bir prosedür önermek, ve bu önerilen prosedür çerçevesinde 9100 DWT'lik çok amaçlı bir kuru yük gemisinin yapısal analizlerini gerçekleştirmektir.

İncelemiş olduğumuz gemi, geniş ambar ağzı açıklıklı ve iki ambarlıdır. Hem iki ambarının olması hem de 170m den küçük olması nedeniyle sınıflandırma kuruluşlarının "burada BV sınıflandırma kuruluşunun kuralları baz alınmıştır" 170m üzeri gemiler için önerdiği gemi ortasındaki üç ambarın modellemesine dayalı direk hesap prosedürü kullanılamamaktadır. Tek ambarın modellemesine dayalı hesap prosedürü (gemi ortasına denk gelen ambar perdesi ile bu perdenin komşuluğundaki ambarların ortalarına kadar olan kısmın modellenmesi ile yapılan analiz) de bu tipte bir gemi için yetersiz kalmaktadır.

Tek ambar analizinin yetersiz kalmasının en önemli nedeni; geminin ambar ağzı açıklıklarının fazla oluşu, bu nedenle de, yükleme durumuna bağlı olarak, ambar ağzı yer değişimlerinin en yüksek değerlerinin ambar ortalarında olmasının beklenmesidir. Sınır koşullarının maksimum yer değişmelerin olduğu bölgelere uygulanması sağlıklı bir analiz yapılabilmesi açısından sakıncalar içermektedir.

Bu analizin neticesinde ambar ağzı yer değişimlerinin tespit edilerek, bu bulunan değerler doğrultusunda bu yer değişmeleri tolere edecek şekilde ambar kapağı dizaynı önerilebilir. Bu durumda ambar ağzı deplasmanlarının doğru tespiti bir kat daha önem kazanmaktadır

Özet olarak, bir prosedür önerilmiş ve bu önerilen prosedür doğrultusunda analizler yapılmıştır. Yapılan analizlerin neticesinde ambar ağızlarında oluşan yer değiştirmeler bulunmuştur. Ayrıca gemi üzerindeki belirli noktalarda bulunan gerilme değerleri de sonuç kısmında belirtilmiştir.

Ayrıca tez içerisinde sonlu elemanlar teorisine matematiksel anlamda değinilmiş, analizde kullanılan paket program hakkında da bilgi verilmiştir, analizde kullanılan eleman formülasyonu matematiksel ve geometrik olarak ifade edilmiştir.

Yapısal analiz aşamasında geminin boyutları ve geometrik özellikleri verilmiş ve bu geminin ANSYS programı içerisinde nasıl modellendiği ayrıntılı olarak anlatılmıştır.

Gemi 9100 DWT kapasiteli, tam boyu 131.07m, kalıp genişliği 17.20m, su çekimi 7.40m, derinliği 9.80m ve servis hızı 13 knot olan çok amaçlı bir kuru yük gemisidir.

Analizi yapılan gem iki ambarlı çok amaçlı bir kuru yük gemisidir. Geminin konteyner taşıma durumu da olduğundan ambar ağzı açıklıklarının geniş olması ve iki ambarlı olması analizi son derece hassas ve de sıkıntılı bir hale sokmaktadır.

BV kurallarında önerilen, üç ambar modelleyerek yapılan analiz prosedürü, analizini yapmak istediğimiz geminin üç ambarı bulunmamasından dolayı, tek ambar analizi de, geminin ambar ağzı açıklıklarının fazla olması ve de sınır koşullarının ambar ortalarına (deformasyonun en fazla olması beklenen bölge) uygulanmasının doğuracağı sakıncalar nedeniyle uygulanmamaktadır. Bu durumda değişik bir prosedür olarak geminin mevcut iki ambarı modellenmek ve de sınır koşulları da ayrıca hesaplanıp modelin uçlarına uygulanmak suretiyle analiz yapılmıştır.

Geminin baş çatışma perdesinden makine dairesi perdesine kadar olan kısmı modellenmiştir. Modelleme daha öncede belirtildiği gibi ANSYS paket programı içerisinde yapılmış hollanda profilleri dahil bütün elemanlar kabul (Shell) eleman olarak modellenmiştir. Elemanın matematiksel formulasyonu ayrıntılı olarak verilmiştir. Kullanılan eleman ANSYS programı içerisindeki Shell 181 dir ve daha ayrıntılı bilgi için ANSYS kullanım kılavuzundan faydalanılabilir.

Modele sac kalınlıkları atanırken yine BV kuralları gereği çeşitli bölgelerdeki korozyon artımları düşülmek suretiyle net kalınlıklar kullanılmıştır.

Model tamamlandıktan sonra sonlu elemanlar ağı oluşturma, kısaca mesh işlemine geçilmiştir. Modelin iki ambar arasında kalan perde ve bu perdeden baş ve kıç doğrultusunda ambar ortalarına kadar olan kısım daha sık ve düzgün meshlenmiş (BV kurallarına göre fine mesh diye tabir edilen,dörtgen elemanın bir kenarı postalar arası mesafenin üçte biri olacak şekilde), ambar ortalarından baş kıç doğrultuda baş çatışma perdesi ve makine dairesi perdesine kadar olan kısım daha seyrek(corse mesh) meshlenmiştir.

Mesh işleminden sonra sonra sınır koşullarının atanmasına geçilmiştir. Geminin orta kesit tarafsız ekseninin merkez hattı ile kesişim noktasında bir düğüm noktası oluşturulmuş ve modelin baş ve kıç kesitindeki düğüm noktaları (nodlar) bütün serbestlik derecelerinde bu belirlenen tarafsız eksendeki düğüm noktası birlikte hareket edecek şekilde sınırlanmıştır (coupling). Daha sonra gemiyi bir kiriş olarak kabul eden analitik çözümden elde edilen deplasman, kuvvet, ve moment değerleri belirlenmiş bu değerler klas kuruluşunun ampirik formüllere bulunan değerleri ile mukayese edilmek ve birleştirmek suretiyle modelin iki ucundan sabitlenen düğüm noktalarına sınır koşulu olarak atanmıştır.

Yükleme koşullarında ise bu sınır koşullarına ek olarak ,zira bu sınır koşulları da kendi başlarına yükleme içermektedir, yine BV kuralları baz ambar içerisine ve denize batan kısmına hidrostatik basınç uygulanmıştır. Uygulanan bu basınç değerleri aslında dinamik etkileri de içinde barındırmaktadır, zira gemi hareketinden kaynaklanan ivme değerleri de bu basınçlar uygulanırken dikkate alınmıştır.

Yapılan analizler neticesinde elde edilen gerilme ve yer değiştirme değerleri tablo ve görsel olarak sunulmuştur. Sonuçlar itibariyle maksimum yer değiştirme değerlerinin 140 mm ile büyük ambarın ortasında oluştuğu görülmüştür.

Ayrıca geminin çeşitli bölgelerinde ve elemanlarında oluşan Von Misses bileşik gerilmeleri ve kayma gerilmeleri değer olarak sunulmuş görsel olarak ifade edilmiştir. Buradan da gerilme değerlerinin klas kuruluğunun güvenlik gerilmeleri sınırlarını aşmadığı görülmüştür.

1. INTRODUCTION

1.1 Ship Manufacture and Scantling

The structural analyse, in other word scantling is the most important phenomena and stages of the ship design. Because of the designer always try to make a ship which has maximum cargo capacity, and minimum light weight. The calculation of wave load and load combinations is the first step in marine structural design. For structural design and analyses, a structural engineers needs to have basic concept of waves, motion and design loads [1].

Once the functional requirements and loads are determined an initial scantling may be sized based on formulae and charts in classification rules and design codes. Basic scantling of the structural components is initially determined based on stress analyses of beams plates and shells under hydrostatic pressure, bending and concentrated loads [1].

1.2 Calculation of Strength via Empirical Formulation

The classification societies have a great experience and their own database related to the every kind and size ships. Using their database and experience they are developing some empirical formulation for scantling of ships. Although these formulations are not based on direct calculation, these also reflect a good approach to the scantling.

1.3 Calculation of Strength via Direct Strength Assessment

The traditional design rule formulae involve a number of simplification, assumptions and can only be used in certain limits. Moreover, scantlings based on rules are not necessarily the most cost efficient designs. Hence, the application of rational stress analysis using FEM has gained increasing attention in the shipbuilding industry.

2. LITERATURE REVIEW

Classification rules have been the main stage of ship design. These rules are primarily semi empirical in nature and have been calibrated to ensure successful operational experience. But with the development of the computation technology, the calculation methods of class societies have been developed accordingly. Nowadays almost all of the class societies have their own procedure for direct calculation method. Although, they are almost same, we explain in this chapter that the direct calculation procedure of BV.

2.1 Procedure, Method and Tools

This procedure deals with the part of the structural analysis which aims at, calculating the stress in the primary supporting members in the midship area, and when necessary, in other areas which are to be used in yielding and buckling checks.

All primary supporting members in the midship region are to be included in three dimensional model, with purpose of calculating their stress level and verifying their scantlings. The application procedure of the analyses based on three dimensional models can be seen in the Figure 2.1

2.2 Modelling and Meshing

The analysis of primary supporting members is to be carried out on fine mesh model. The longitudinal extension of the structural model is to be such that, the hull girder stress in the area to be analysed are properly taken into account in the structural analysis, the result in the areas to be analysed are not influenced by the unavoidable inaccuracy in the modelling of the boundary conditions.

In general for multi hole ships more than 170 m in length, the condition mentioned above are considered as being satisfied when the model extended over at least three cargo hold which can be seen in Figure 2.2

There are some criteria of finite element modelling according to the BV rules.

- The analysis of primary supporting members based on fine mesh models is to be carried out by applying one of the following procedures, depending on the computer resources:

  • an analysis of the whole three dimensional model based on a fine mesh

  • an analysis of the whole three dimensional model based on a coarse mesh, from which the nodal displacements or forces are obtained to be used as boundary conditions for analyses based on fine mesh models of primary supporting members [14].

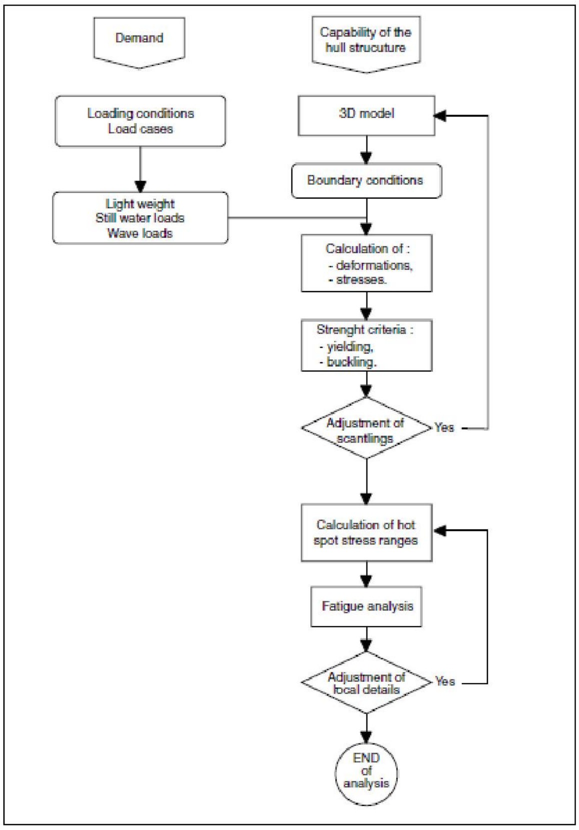

Figure 2.1 : Application procedure of the analyses based on three dimensional models.

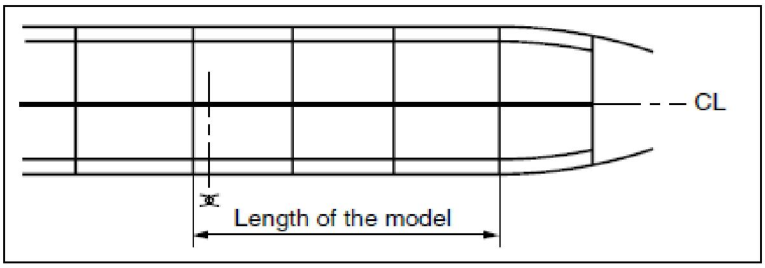

Figure 2.2 : Model longitudinal extension ships more then 170m in length.

For ships less than 170 m in length, the model may be limited to one cargo hold (one half cargo hold length on either side of the transverse bulkhead.) which can be seen in Figure 2.3.

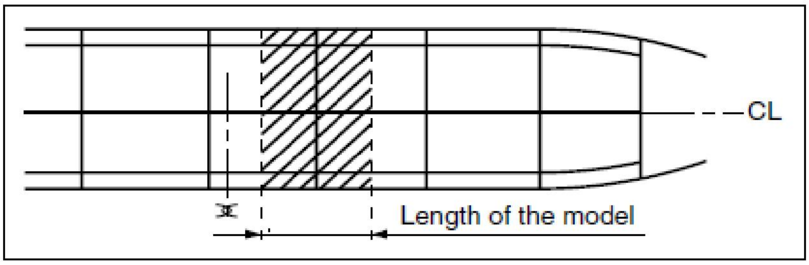

Figure 2.3 : Model longitudinal extension ships less than 170m in length.

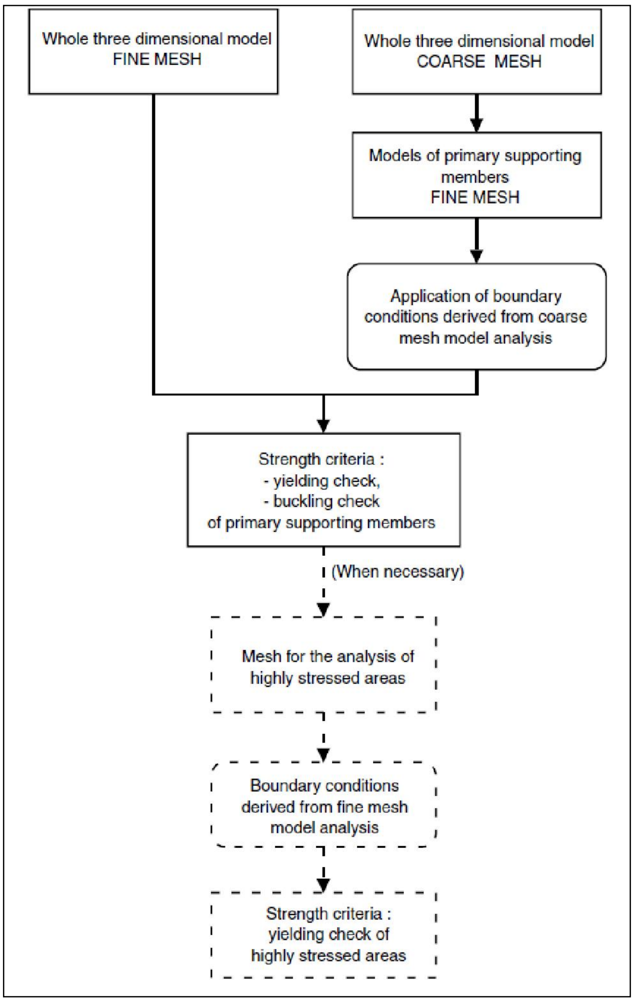

Figure 2.4 : Finite element modelling criteria.

2.3 Loading and Boundary Condition

The hydrostatic water pressure is to be applied to the outside hull with increasing the gravity as acceleration calculated from related class rules. For cargo hold, cargo load weight are to be applied increasing the gravity same as sea pressure. And Global bending moment and sheering forces are to be applied at the end of the model in order to ensure maximum bending moment at the middle of the ship [14].

Structural model extended over at least three cargo tank/hold lengths; the whole three dimensional model assumed to be fixed at one end, while shearing force, and bending moments are applied at the other end to ensure the equilibrium. At the free end section, rigid constraint conditions are to be applied to all nodes located on longitudinal members, in such a way that the transverse section remains plane after deformation [14].

Structural models extended over one cargo tank/hold length Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Table 2.1.

Table 2.1 : Symmetry condition at the model fore and aft ends.

DISPLACEMENTS in directions			ROTATION around axes		
X	Y	Z	X	Y	Z
fixed	free	free	free	fixed	fixed

3. FINITE ELEMENT METHOD

3.1 Finite Element Theory

The finite element method is basically a numerical method for solving differential equation. The finite element method generates discrete models for continuous system. The basic concept of the finite element method is the same as in matrix frame analyse, that the structure can be represented as an assembly of individual structural elements interconnected at discrete number of nodes. Continuous structure such as panel of plates,

The First step creating finite element model for solid objects or structure is to divide into finite number of discrete elements. There are usually selected from a library of element types available within a given program. The element which is selected for this work was described in chapter 4.

Each element is characterized by its own topology (an order of sequences of point or nodes.), and by a number of material or structural property such as density, elasticity module and young module.

Elements which carry loads in bending such as beams and plates are termed as structural elements. They are more complex, since their formulation incorporate aspects of beam and plate theory such as “plane section remain plane “, and involves curvature and moments rather than simple stress and strain.

The form of the finite element equation can be described simply as; the displacement at any point in structure due to the combined application of all external loads is equivalent to the sum of the displacement at the same point due to the application of the load separately, moreover the displacement at any point due to the application of each load varies linearly with the magnitude of load.

These statements are given mathematical expression by defining quantity as the contribution to the displacement which results from the application of a nodal force in the absence of other loads. So it may be written as:

$$
\begin{aligned}
&\delta_1 = \delta_{11} + \delta_{12} + \delta_{13} \ldots\ldots + \delta_{1n} \\
&\delta_2 = \delta_{21} + \delta_{22} + \delta_{23} \ldots\ldots + \delta_{2n} \\
&. \\
&. \\
&\delta_n = \delta_{n1} + \delta_{n2} + \delta_{n3} \ldots\ldots + \delta_{nn}
\end{aligned}
\tag{3.1}
$$

These statements also implies the existence of a constant of proportionality which determines the contribution made by the load f_j to the displacement δ_{ij}.This constant is termed the "flexibility influence coefficient" and defined as:

$$\delta_{ij} = c_{ij} f_j \tag{3.2}$$

Leaving aside, the problem of actually calculating these quantities, we can substitute equation 3.2 into 3.1 to produce a system of linear equations which relate the nodal displacement to the nodal forces. These are;

$$
\begin{aligned}
&\delta_1 = c_{11} f_1 + c_{12} f_2 + \ldots\ldots + c_{1n} f_n \\
&\delta_2 = c_{21} f_1 + c_{22} f_2 + \ldots\ldots + c_{2n} f_n \\
&. \\
&. \\
&\delta_n = c_{n1} f_1 + c_{n2} f_2 + \ldots\ldots + c_{nn} f_n
\end{aligned}
\tag{3.3}
$$

They may be expressed more concisely in matrix form as;

$$d = Cf \tag{3.4}$$

Where;

$$
d = \begin{bmatrix} \delta_1 \\ \delta_2 \\ . \\ . \\ . \\ \delta_n \end{bmatrix}, C = \begin{bmatrix} c_{11} c_{12} \ldots\ldots\ldots\ldots c_{1n} \\ c_{21} c_{22} \ldots\ldots\ldots\ldots c_{2n} \\ . \\ . \\ . \\ c_{n1} \ldots\ldots\ldots\ldots\ldots\ldots c_{nn} \end{bmatrix}, f = \begin{bmatrix} f_1 \\ f_2 \\ . \\ . \\ . \\ f_n \end{bmatrix}
\tag{3.5}
$$

The matrix C has n rows and n columns and is termed the flexibility matrix. Matrix f and d are termed the nodal force vector and the nodal displacement vector, respectively.

To understand the structure of the equivalent finite element equations, it is helpful to consider the equations which would result if equation 3.4 were inverted, both sides of the equation 3.4 can be multiplied by inverse of C to give;

$$C^{-1}d = f \tag{3.6}$$

The matrix C^{-1} is the "stiffness matrix" of the system. It is usually denoted by the symbol K, and above equation is written.

$$Kd = f \tag{3.7}$$

In finite element formulation, the coefficients of the stiffness matrix K are obtained directly from the structure without reference flexibility coefficient.

The solution of equation 3.7 gives the nodal displacement of structure. After these have been found, the strain within each element can be determined as well. The finite element model represents, in this sense, a displacement method of analyse, because the displacement of the structure are the primary unknown quantities and are calculated first.

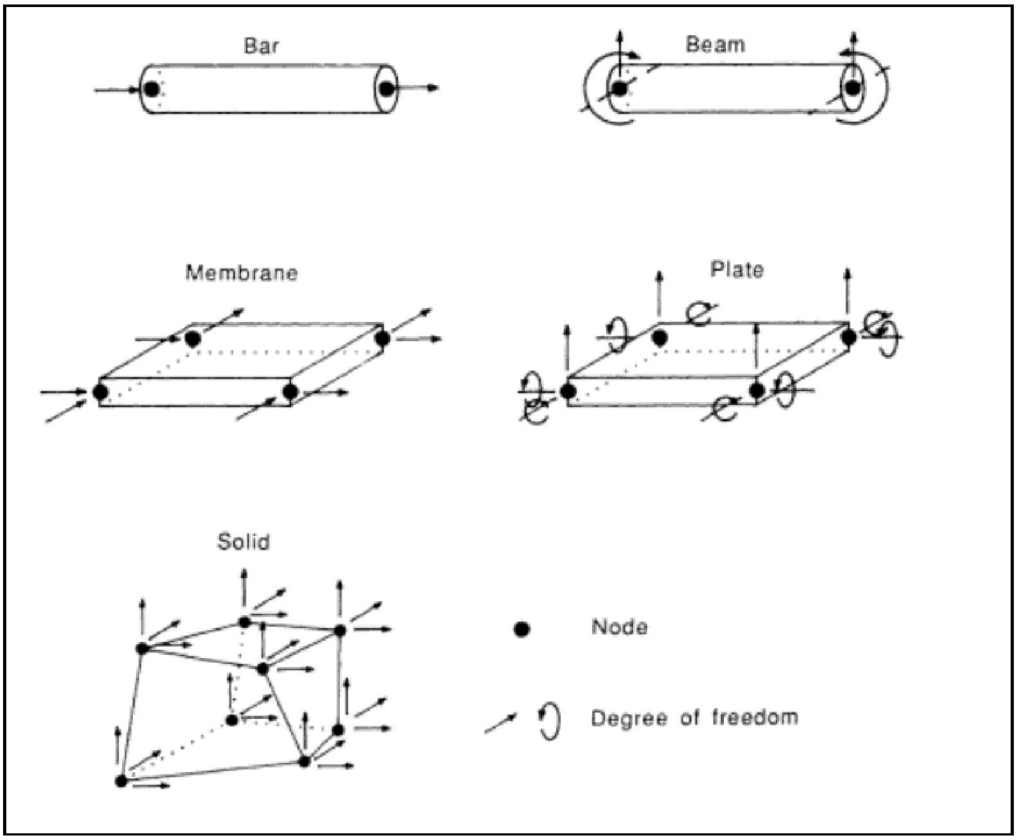

Figure 3.1 : Element type.

This is very basic explanation of finite element method, depending on the element selection it may be more complex form. Although it is main aim to give a new kind of strength calculation method by conventional pocket program for this paper, theorical explanation of method was kept simple.

3.2 Conventional Pocket Programme

When we create model in conventional package programme, like Ansys, first of all we create a solid model of structure that will be analysed, and than the solid model is converted to the finite element model via mesh generation. This transformation ensures us to define our model by nodes. These nodes are converted to the stiffness matrix by using a special algorithm at background, depending on used coordinate axis as well. Applied loads are also converted to the load vector. After the generation of stiffness matrix and load vector, the equation is established, and transferred to the solver. There is a linear algebraic equation, and can be solved by arbitrary method.

All of the conventional package programme use almost same style except modelling stages. We used Ansys in order to carry out our structural analyse. The analyses sequence was given in chapter 4.

4. STRUCTURAL ANALYSIS OF MULTI PURPOSE SHIP

4.1 Introduction

The aim of this analysis is to investigate the structural endurance of main cargo tanks construction of 9100 DWT Multi Purpose Ship. For this reason two cargo hold and the bulkhead between two cargo hold have been modelled. Basically BV rules have been taken into account for calculation. The analysis procedure has been explained in chapter 2. Although, basically we follow these procedures, we will make a special procedure.

The ship which we analysed has two cargo hold and 130m in length. Therefore we can not apply three cargo analysis procedure. We carried out one cargo hold analysis procedure by modelling two cargo hold without end bulkhead, including middle bulkhead and finely meshing middle part (from the middle of the first cargo hold to the middle of the second cargo hold), and coarsely meshing the other part of the mode. This kind of modelled has been chosen in order to apply boundary condition more correct, and handle more correct solution at the middle of the cargo holds. Because if we apply boundary condition at the middle of the cargo holds, we can not handle good solutions at these areas.

As a result we applied one cargo hold procedures by taking the load values from class rules, which is presented in section 4.3 detaily, with modelling two cargo hold. Although it is out of class procedure, we think it is better to use these kind of analysis method to ensure more accurate solution.

First of all we calculated pressure values for our model from class rules, than these pressure values were applied to the model, and the maximum moment value which occurred on the model were calculated. Than we calculated moment values from the class rules and found the difference between the moments occurred in the model and calculated from class rules, and by adding these difference moment values to the model, we shifted the moment of the model correct value. Same procedures were applied for shearing forces.

Model was fixed at both ends as applying rigid region with base point which is placed at the natural axis, and these difference moment values were applied to these points. For tensional moment, which is in the load case C, there is a point which placed at shear centre, and the tensional moment was applied from this point.

Then, the analyses were carried out, and results were presented.

4.1.1 Main dimensions

Length Overall	131.07m
Length Between P.P	123.20m
Breadth Moulded	17.20m
Depth Moulded	9.80m
Scanting Draught	7.40m
Deadweight	9100ton
Speed	13knot

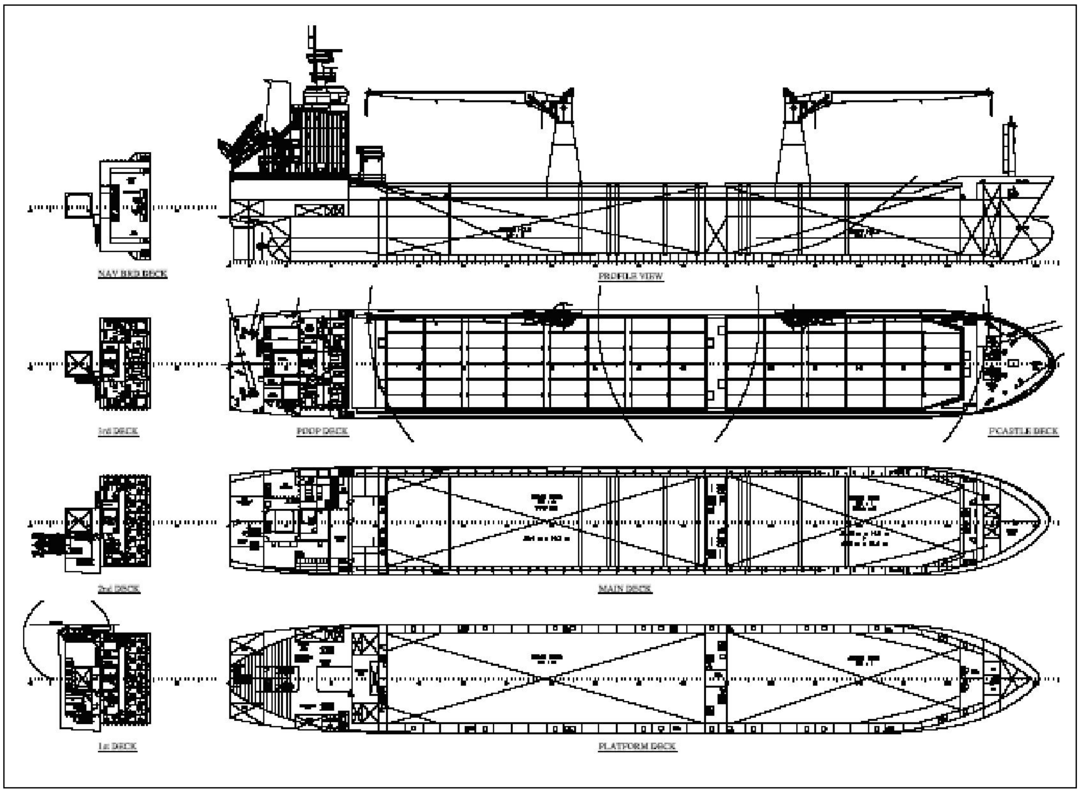

Figure 4.1 : General arrangement.

4.2 Modelling Stage

The ship has two cargo tanks; although it is aimed that one cargo tank analyzed, all of the cargo tanks has been modelled, including middle bulkhead and excluding aft and fore bulkhead, because of applying more accurate boundary condition. The extension of the model can be seen in Figure 4.2 below.

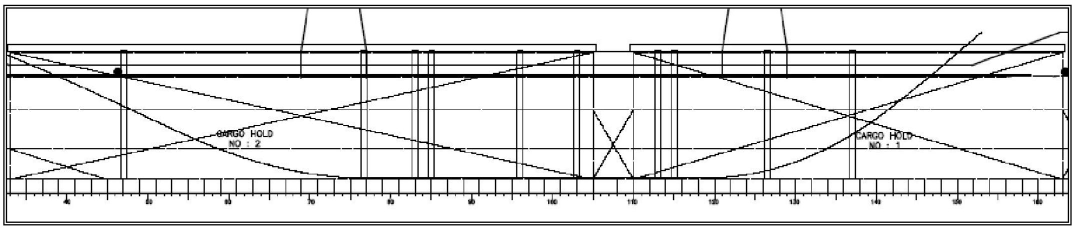

Figure 4.2 : Extension of the finite element model.

4.2.1 Solid modelling stage

The solid model is prepared in Ansys software and can be seen in Figures 4.3 to 4.5 below. In these Figures different colours indicate different thickness values and the detailed outputs of thickness values can be seen in Appendix I. In the definition stage of the thickness values, the corrosion additions are also taken into account according to BV Rules, Part B, Chapter 4, Section 2, [3] Table 4.2. Thickness values can be seen in Appendix I without corrosion additions. The ship has two cargo hold as can be seen figure Figure 4.1. Both cargo holds have been modelled with all primary structural members, such as longitudinal frames, girders, and webs with manhole and face plates, bulkhead excluding fore most, and aft bulkheads. End bulkhead have been excluded because, we have applied the boundary condition from these locations.

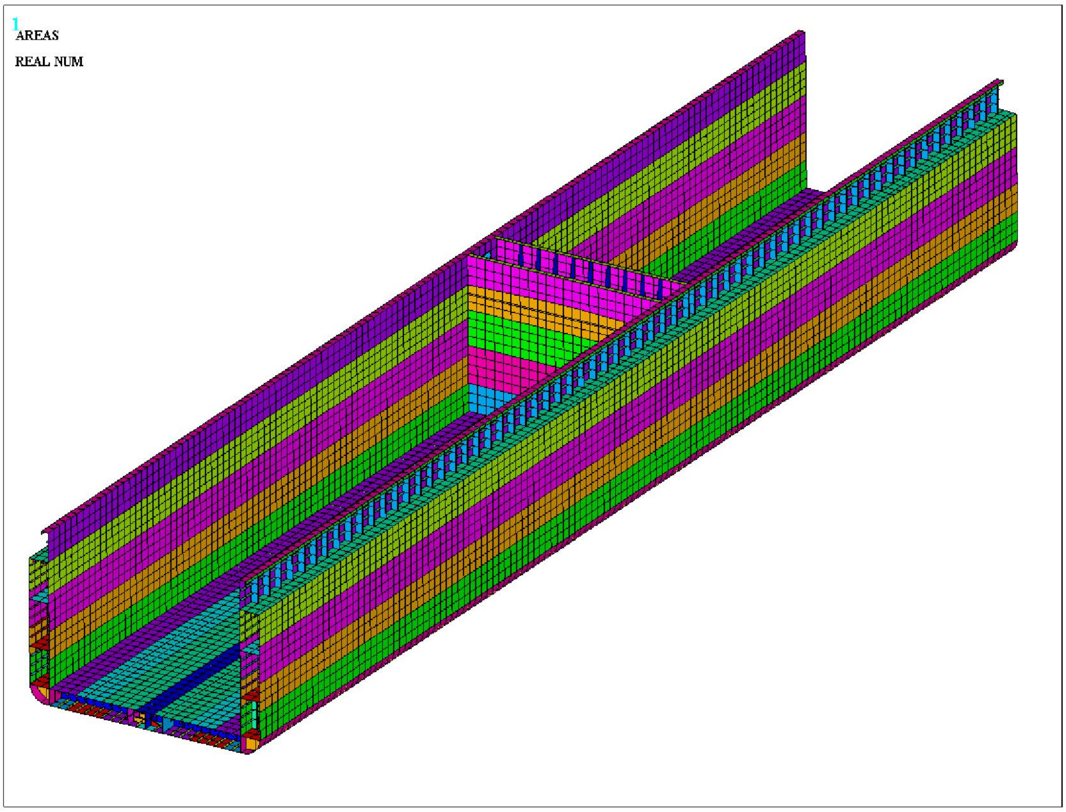

Figure 4.3 : Solid model.

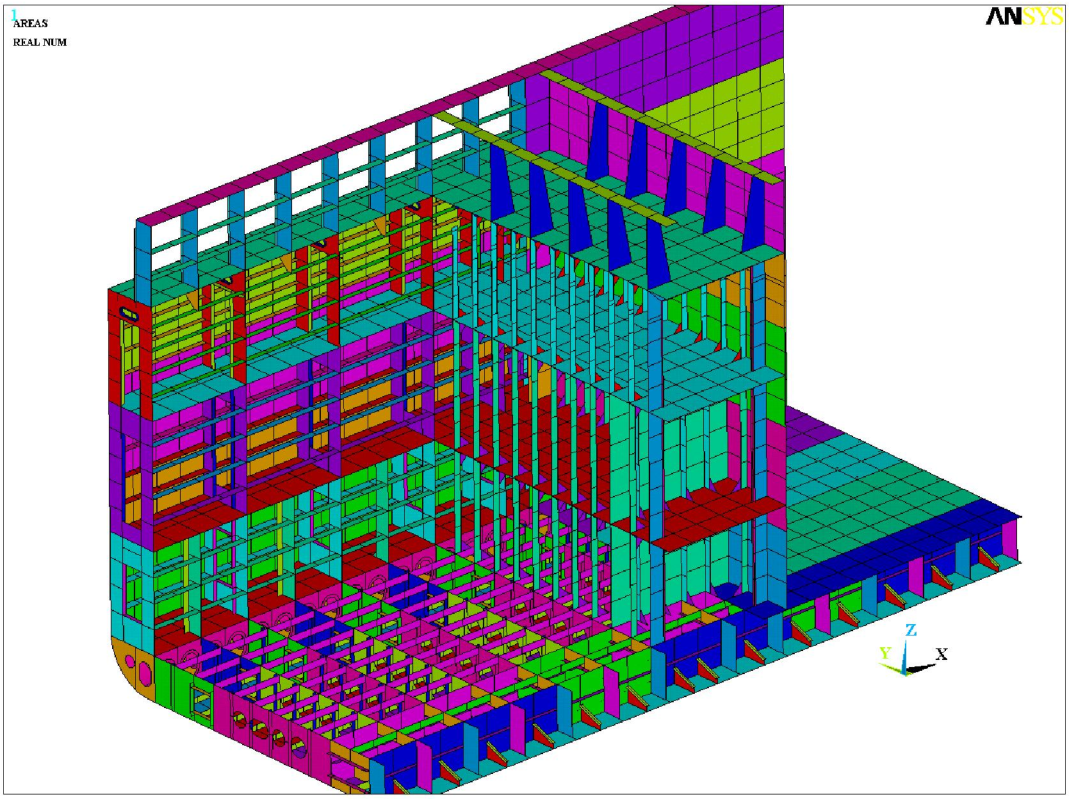

Figure 4.4 : Solid model (Bulkhead).

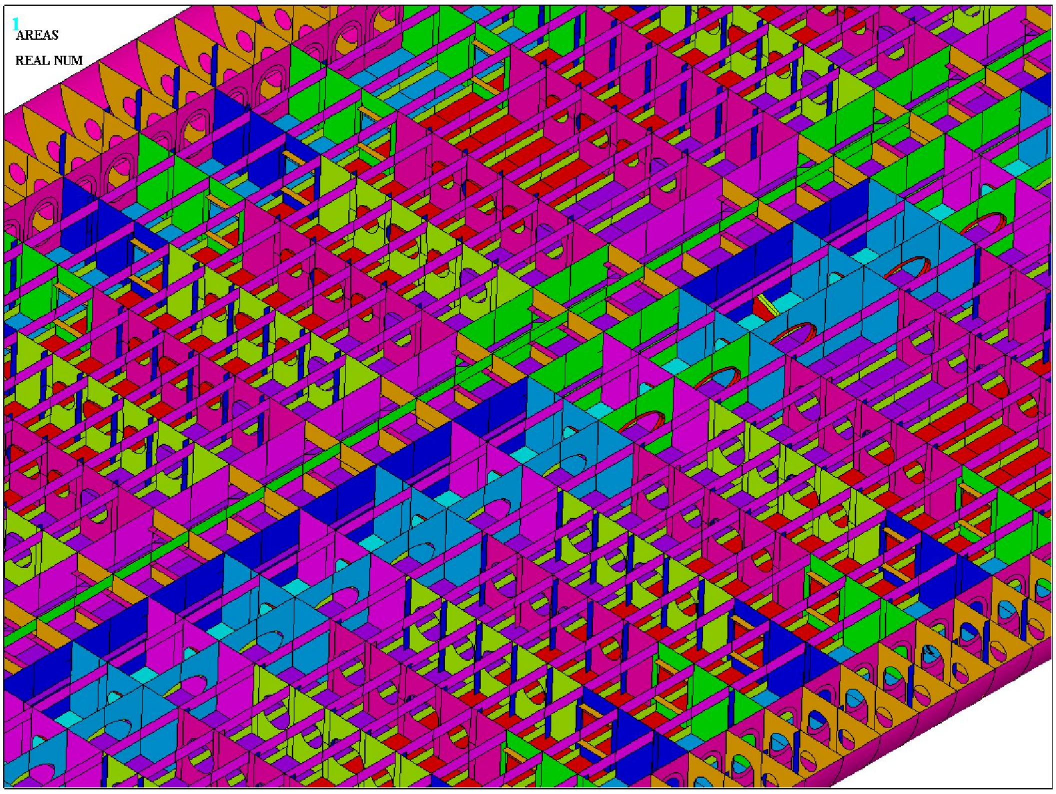

Figure 4.5 : Solid model (Bottom).

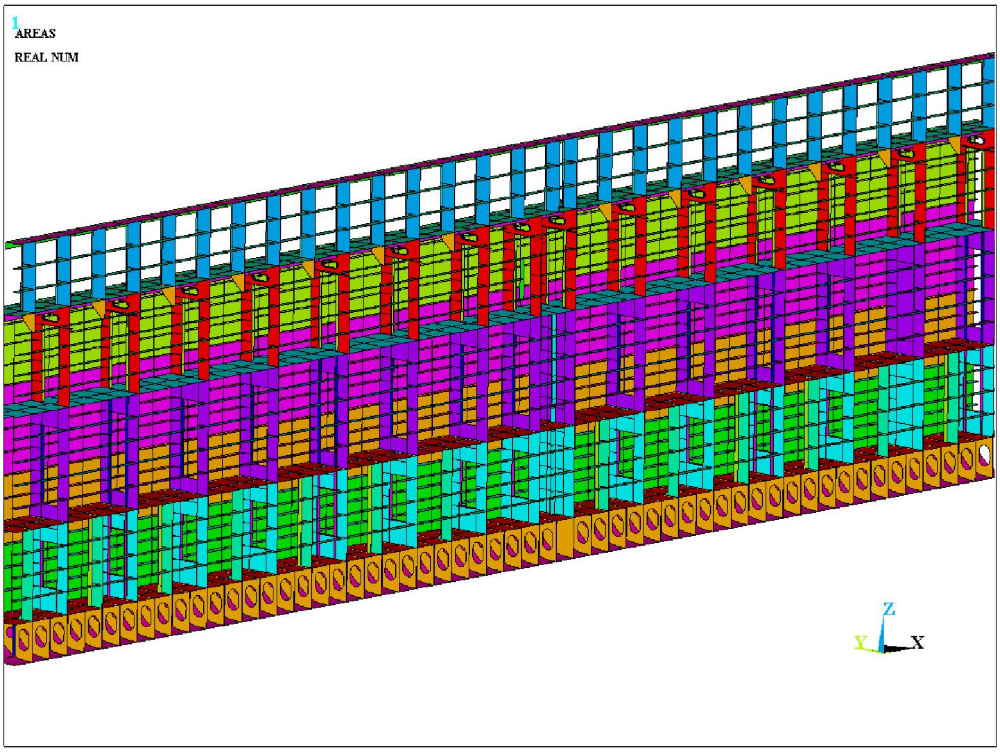

Figure 4.6 : Solid model (Side).

4.2.2 Mesh modelling stage

Ansys solid model is meshed by using the Ansys specific elements Shell63. This element is used for all plating parts, and profiles. The properties of this element are given below Figure 4.7.

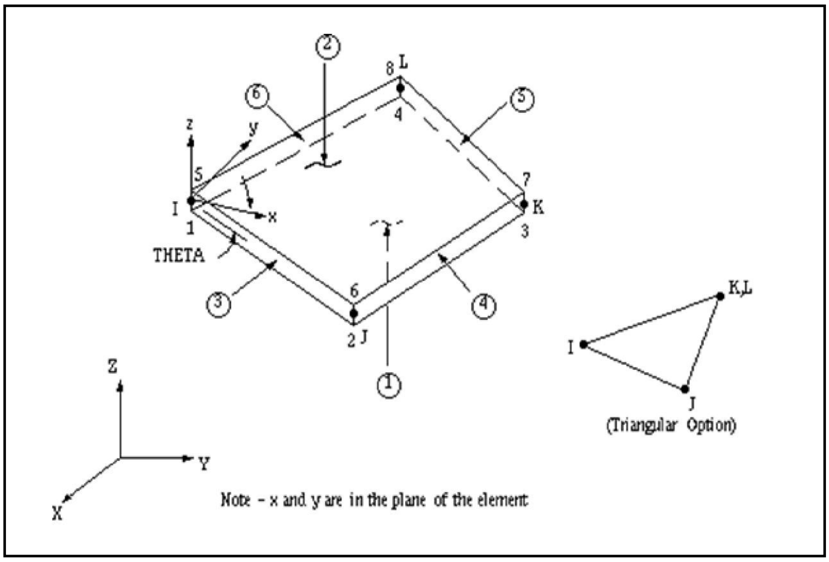

Figure 4.7 : Shell 63 element.

SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes.

Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses. This element can be seen in Figure 4.7.

After the meshing operations are completed, it is seen that the finite element model has 195449 nodes and 211187 elements in total. The finite element model can be seen in Figures 8 to 11.

Because of the fact that, we focused on the middle of the ship (from the middle of the first tank to the middle of the second tank) the finite element model is considered as finely meshed according to the BV rules Pt B, Ch 7, App. 1 3.4.3. at this zone (from the middle of the first tank to the middle of the second tank). The other part of the model is considered as course mesh.

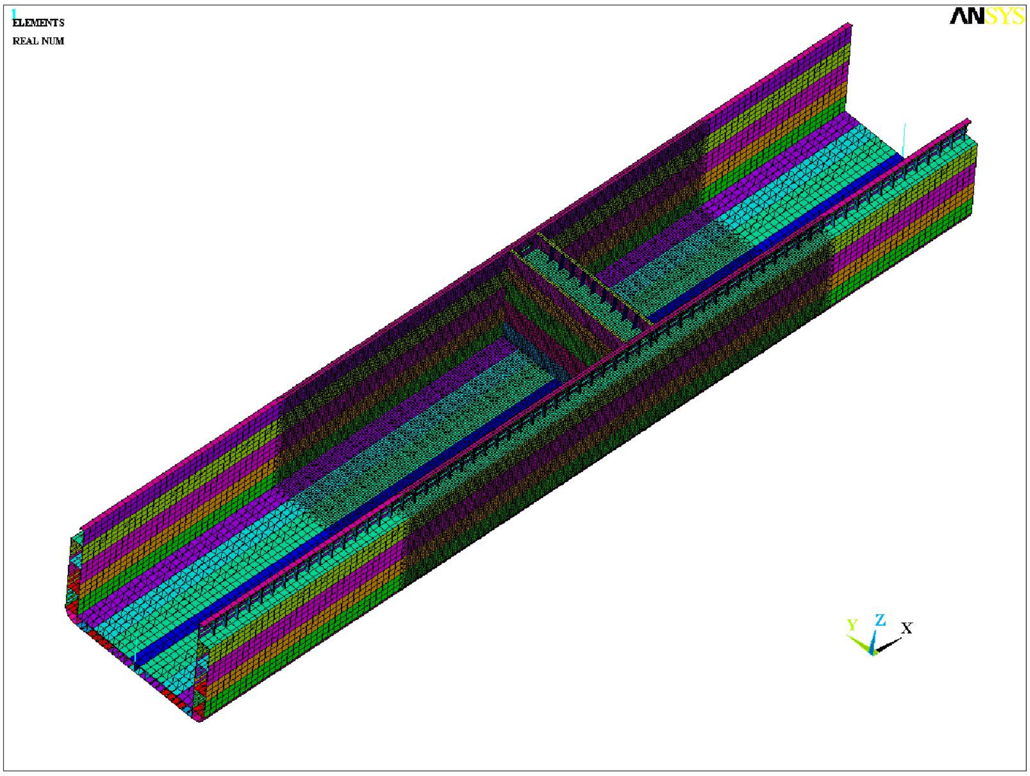

Figure 4.8 : Mesh density of the finite element model.

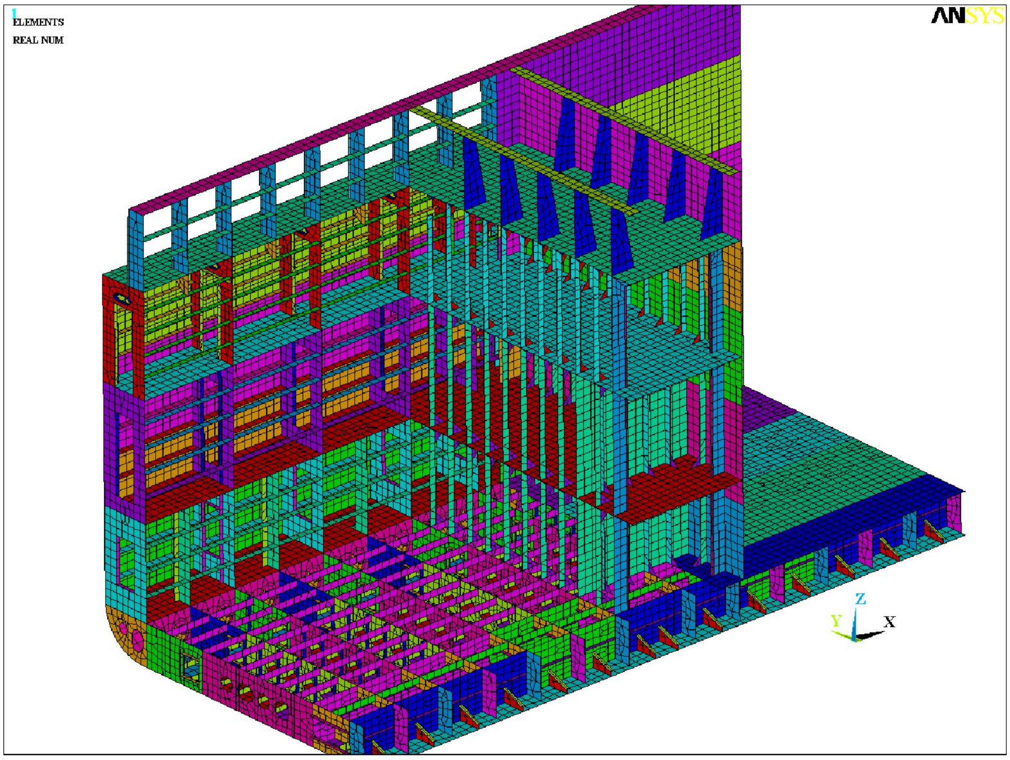

Figure 4.9 : Mesh density of the finite element model (Bulkhead).

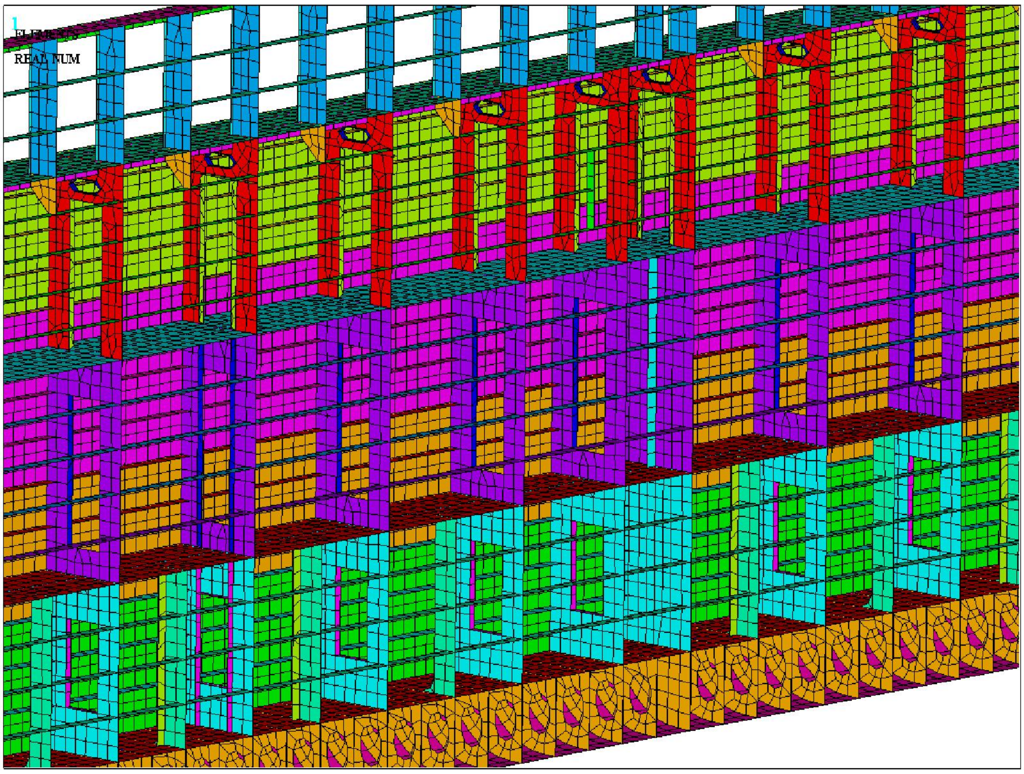

Figure 4.10 : Mesh density of the finite element model (Side).

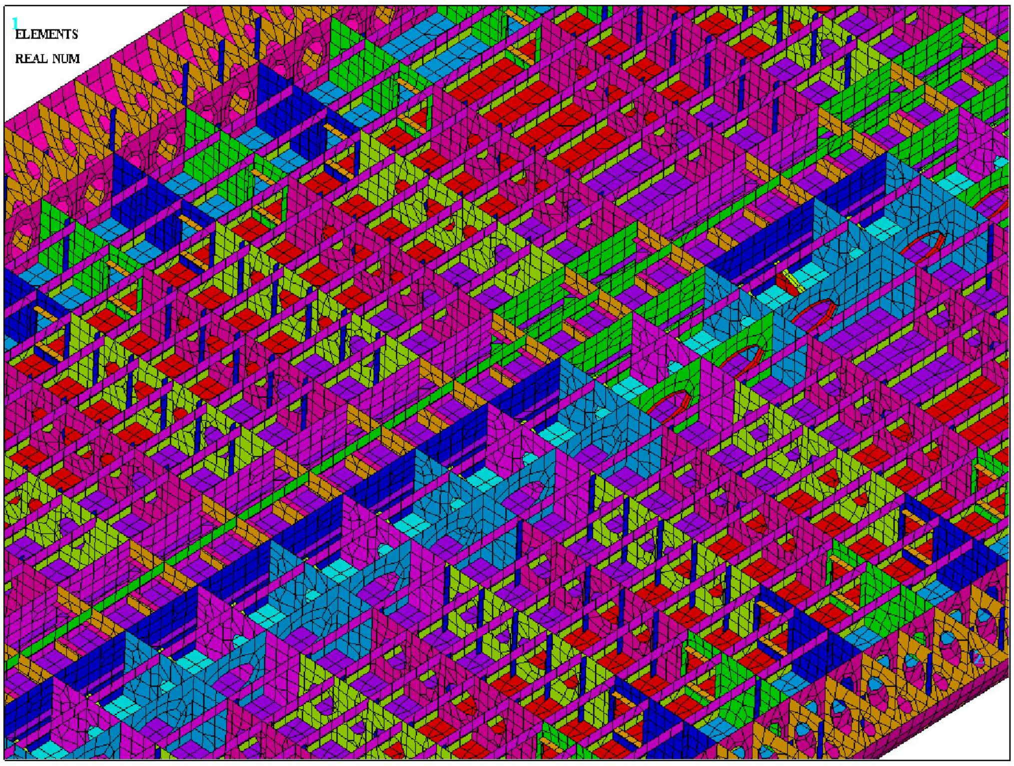

Figure 4.11 : Mesh density of the finite element model (Bottom).

4.2.3 Material properties

The material for the steel used in the ship is St 42, AH 36 grade shipbuilding steel and their properties are given below

• Elasticity modulus = 210000 N/mm2

• Poisson ratio = 0.30

• Density = 7850 kg/m3

4.3 Boundary and Loading Condition

4.3.1 Boundary conditions

The nodes at the aft and fore end cross sections are coupled to section's centre nodes near to the natural axis and simple supported boundary conditions (ux, uy, uz, Rx, Rz are fixed for aft end and uy and uz are fixed for fore end) are applied for loading condition A,B, and C. These centre nodes are also to be used to apply the global bending and wave induced moment values. In load case C Rz was not fixed in order to applying horizontal bending moment correctly, and for applying torsional moment additional key point has been created. Boundary conditions can be seen in Figure12 below.

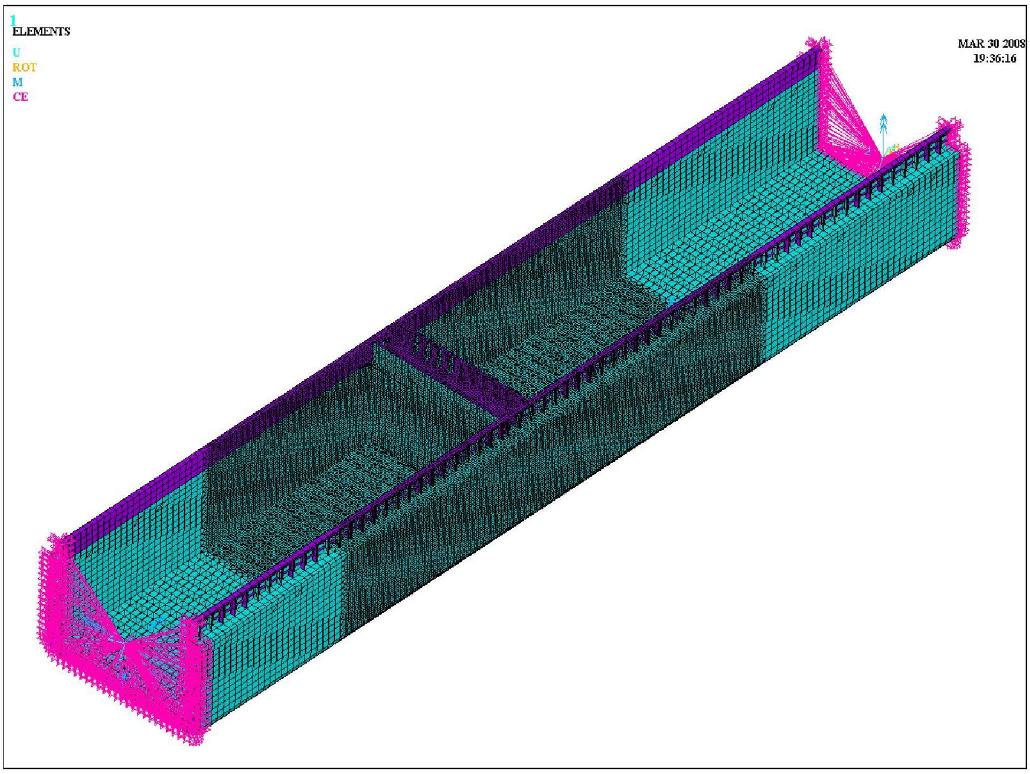

Figure 4.12 : Boundary conditions.

4.3.2 Loading conditions

It is aimed to get the worst loading condition for ship structure. Therefore load case A B, and C according to the BV rules were applied to the model, lightship weight was also included in these load case as double bottom load. The quasi static analysis has been carried out. It means; static analysis was carried out by taking in the account the dynamic effects by including the acceleration. The loads applied to the model can be classified in four groups, such as; sea pressure, internal pressure, moments, and shear forces.

Sea pressure is composed by two parts; still water pressure (hydrostatic pressure applied by se to ship hull), and wave pressure.

Sea water pressure at any point of the hull is obtained from the formula as follows;

$$p_s = \rho g(T - z) \qquad \textbf{(4.1)}$$

z is the point which you want the learn the pressure value, and if it is chosen grater than T, p_s is equal to 0.

Wave pressure depending on the load case can be calculated from the formula given in the Tables 4.1 and 4.2.

Table 4.1 : Wave pressure for load cases C.

Wave pressure in inclined ship conditions (load cases "c" and "d")

Location	Wave pressure p_W, in kN/m² (negative roll angle)	
	$y \geq 0$	$y < 0$
Bottom and sides below the waterline ($z \leq T_1$)	$C_{F2}\rho g\left[\frac{y}{B_W}h_1 e^{\frac{-2\pi(T_1-z)}{L}} + A_R y e^{\frac{-\pi(T_1-z)}{L}}\right]$	$C_{F2}\rho g\left[\frac{y}{B_W}h_1 e^{\frac{-2\pi(T_1-z)}{L}} + A_R y e^{\frac{-\pi(T_1-z)}{L}}\right]$ without being taken less than $\rho g (z - T_1)$
Sides above the waterline ($z > T_1$)	$\rho g\left[T_1 + C_{F2}\left(\frac{y}{B_W}h_1 + A_R y\right) - z\right]$ without being taken, for case "c" only, less than 0,15 L	0
Exposed decks	$0{,}4\rho g\left[T_1 + C_{F2}\left(\frac{y}{B_W}h_1 + A_R y\right) - z\right]$ without being taken, for case "c" only, less than 0,15 φ_1 φ_2 L	0

Note 1:
φ_1 : Coefficient defined in Tab 2
φ_2 : Coefficient defined in Tab 4
C_{F2} : Combination factor, to be taken equal to:
- C_{F2} = 1,0 for load case "c"
- C_{F2} = 0,5 for load case "d"

B_W : Moulded breadth, in m, measured at the waterline at draught T_1, at the hull transverse section considered
A_R : Roll amplitude, defined in Ch 5, Sec 3, [2.4.1].

Table 4.2 : Wave pressure for load cases A and B.

Wave pressure on sides and bottom in upright ship conditions (load cases "a" and "b")

Location	Wave pressure p_W, in kN/m²	
	Crest	Trough (1)
Bottom and sides below the waterline ($z \le T_1$)	$\rho g h e^{\frac{-2\pi(T_1 - z)}{L}}$	$-\rho g h e^{\frac{-2\pi(T_1 - z)}{L}}$ without being taken less than $\rho g (z - T_1)$
Sides above the waterline ($z > T_1$)	$\rho g (T_1 + h - z)$ without being taken, for case "a" only, less than 0,15 L	0,0

(1) The wave pressure for load case "b, trough" is to be used only for the fatigue check of structural details (see Ch 7, Sec 4).

Note 1:

$h = C_{F1} h_1$

C_{F1} : Combination factor, to be taken equal to:

- $C_{F1} = 1{,}0$ for load case "a"
- $C_{F1} = 0{,}5$ for load case "b".

Internal pressure is composed by two parts; cargo hold load with increasing the gravitational acceleration as corresponding calculated acceleration according to the load cases, and light weight load.

The still water and inertial pressure are obtained in kN/m^2 as specified in table 4.3.

Table 4.3 : Internal pressures.

Dry uniform cargoes Still water and inertial pressures

Ship condition	Load case	Still water pressure p_S and inertial pressure p_W, in kN/m²
Still water		The value of p_S is generally specified by the Designer; in any case, it may not be taken less than 10 kN/m². When the value of p_S is not specified by the Designer, it may be taken, in kN/m², equal to 6,9 h_{TD} , where h_{TD} is the compartment 'tweendeck height at side, in m.
Upright (positive heave motion)	"a"	No inertial pressure
	"b"	$p_{W,Z} = p_S \frac{a_{Z1}}{g}$ in z direction
Inclined (negative roll angle)	"c"	$p_{W,Y} = p_S \frac{C_{FA} a_{Y2}}{g}$ in y direction
	"d"	$p_{W,Z} = p_S \frac{C_{FA} a_{Z2}}{g}$ in z direction

With using formulas for a_B and h_W given below and table 4.4 the acceleration values can be calculated.

$$a_B = n_1(0.76F + 1.875\frac{h_W}{L}) \qquad \textbf{(4.2)}$$

$$h_W = 11,44 - \left|\frac{L-250}{110}\right| \quad \text{for; } L<350 \qquad \textbf{(4.3)}$$

Table 4.4 : Acceleration values.

Pitch amplitude, period and acceleration

Amplitude A_P, in rad	Period T_P, in s	Acceleration α_P, in rad/s²
$0{,}328 a_B\left(1{,}32 - \frac{h_W}{L}\right)\left(\frac{0{,}6}{C_B}\right)^{0{,}75}$	$0{,}575\sqrt{L}$	$A_P\left(\frac{2\pi}{T_P}\right)^2$

Sway period and acceleration

Period T_{SW}, in s	Acceleration a_{SW}, in m/s²
$\frac{0{,}8\sqrt{L}}{1{,}22F+1}$	$0{,}775\ a_B\ g$

Roll amplitude, period and acceleration

Amplitude A_R, in rad	Period T_R, in s	Acceleration α_R, in rad/s²
$a_B\sqrt{E}$ without being taken greater than 0,35	$2{,}2\frac{\delta}{\sqrt{GM}}$	$A_R\left(\frac{2\pi}{T_R}\right)^2$

Moments and shearing forces are calculated directly from the rules as below explained.

$$M_{SWM,H} = 175 n_1 C L^2 B (C_B + 0,7) 10^{-3} - M_{WV,H} \qquad \textbf{(4.4)}$$

$$M_{SWM,S} = 175 n_1 C L^2 B (C_B + 0,7) 10^{-3} + M_{WV,S} \qquad \textbf{(4.5)}$$

C is the wave parameter, and calculated as follows;

$$C = 10,75 - \left(\frac{300-L}{100}\right)^{1,5} \quad \text{for} \quad 90\text{m}|<L<300\text{m} \qquad \textbf{(4.6)}$$

n_1 is the navigation coefficient, and it is taken 1 for unrestricted navigation.

The vertical wave bending moments at any hull transverse section are obtained from the following formula in k Nm.

Hogging conditions:

$$M_{WV,H} = 190\, F_M n_1 C L^2 B C_B 10^{-3} \tag{4.7}$$

Sagging conditions:

$$M_{WV,S} = 110\, F_M n_1 C L^2 B (C_B + 0,7) 10^{-3} \tag{4.8}$$

The horizontal wave bending moment at any hull transverse section are obtained from the following formula in k Nm.

$$M_{WH} = 0,42 F_M n_1 H L^2 T C_B \tag{4.9}$$

H is the wave parameter, and calculated as follows;

$$H = 8.13 - \left(\frac{250 - 0,7L}{125}\right)^3 \tag{4.10}$$

The values of the wave torque at any transverse section are calculated, with respect to section centre of torsion, with following formula.

$$M_{WT} = \frac{HL}{4} n_1 (F_{TM} C_M + F_{TQ} C_Q d) \tag{4.11}$$

C_M is wave torque coefficient, and calculated as follows;

$$C_M = 0,45 B^2 {C_W}^2 \tag{4.12}$$

C_Q is horizontal wave shear coefficient, and calculated as follows;

$$C_Q = 5 T C_B \tag{4.13}$$

d is the vertical distance, in m, from the centre of torsion to a point located at 0,6T above the base line.

The vertical shear forces at any hull transverse section are obtained from the following formula in k N.

$$Q_{WV} = 30 F_Q n_1 C L B (C_B + 0,7) 10^{-2} \tag{4.14}$$

F_M , F_{TM} , F_{TQ} values can be taken from the Figure 4.13 below.

The moment values, applied directly to the model can be calculated using table 4.5.

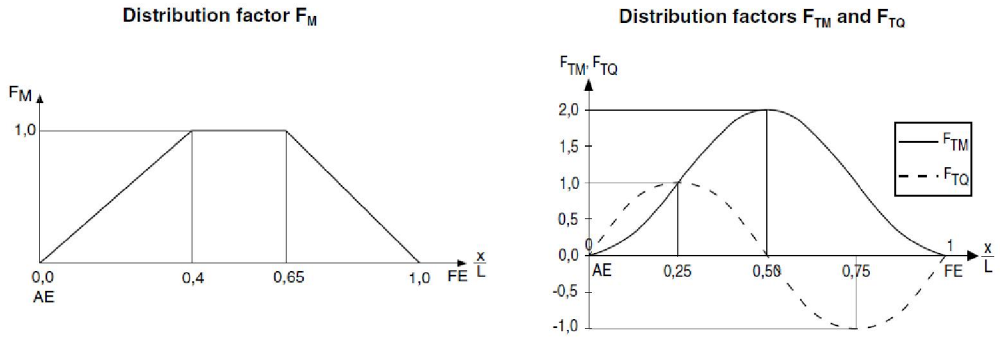

Figure 4.13 : F_M , F_{TM} , F_{TQ} values.

Table 4.5 : The moment values, applied directly to the model.

Hull girder loads for a structural model extended over one cargo tank/hold length

Ship condition	Load case	Vertical bending moments at the middle of the model		Horizontal wave bending moment at the middle of the model	Vertical shear forces at the middle of the model	
		Still water	Wave		Still water	Wave
Upright	"a" crest	$\gamma_{S1} M_{SW}$	$0{,}625\ \gamma_{W1} M_{WV,H}$	0	$\gamma_{S1} Q_{SW}$	$0{,}625\ \gamma_{W1} Q_{WV}$
	"a" trough	$\gamma_{S1} M_{SW}$	$0{,}625\ \gamma_{W1} M_{WV,S}$	0	$\gamma_{S1} Q_{SW}$	$0{,}625\ \gamma_{W1} Q_{WV}$
	"b"	$\gamma_{S1} M_{SW}$	$0{,}625\ \gamma_{W1} M_{WV,S}$	0	$\gamma_{S1} Q_{SW}$	$0{,}625\ \gamma_{W1} Q_{WV}$
Inclined	"c"	$\gamma_{S1} M_{SW}$	$0{,}250\ \gamma_{W1} M_{WV}$	$0{,}625\ \gamma_{W1} M_{WH}$	$\gamma_{S1} Q_{SW}$	$0{,}250\ \gamma_{W1} Q_{WV}$
	"d"	$\gamma_{S1} M_{SW}$	$0{,}250\ \gamma_{W1} M_{WV}$	$0{,}625\ \gamma_{W1} M_{WH}$	$\gamma_{S1} Q_{SW}$	$0{,}250\ \gamma_{W1} Q_{WV}$

Note 1: Hull girder loads are to be calculated at the middle of the model.

The summary of these load cases can be seen from the Figure 4.14 below.

The loads, which are applied to the model directly, as result of presented calculation, and explained shifting operation, are summarized in the Table 4.6. All the formulas given above have been taken from BV rules Section B Chapter 5, and detailed explanation of this formulation can be found in this Rule Book.

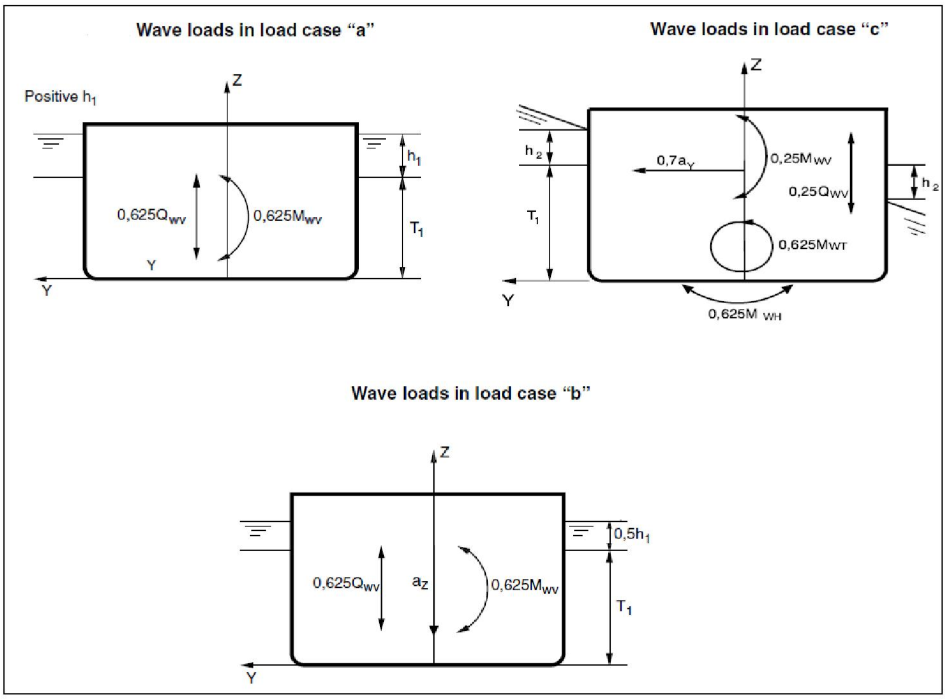

Figure 4.14 : The summary of load cases.

Table 4.6 : Load summary.

	Loading Cases		
Sea Load	A	B	C
Double Bottom Pressure (kN/m2)	101	140	113
Msw	-180000	-180000	-180000
Mwv	342000	-368000	-368000
Maximal Vertical Bending Moments (kNm)	55125	-433000	-281200
Maximal Horizontal Bending Moments (kNm)	0	0	-253000
Torsional Moment (kNm)			50000

4.4 Results

In this work I tried to carry out structural analyses of a 9100 DWT multi purpose ship. The subjected vessel has large deck openings, because of that we focused on the deflections, which occur on the way of hatchway coamings. These deflections value are important also for the manufacturing of the hatch cover. These deflection values must be taken in to account, when manufacturing of the hatch cover.

The displacement values of the hatchcoaming of cargo hold No:2 which is in between frame number 32 to frame number 105 are presented in Table 4.7 below. The displacement values are absolute value in this table. In load case A and B displacements are through inside the cargo hold, and in load case C displacements are through outside the cargo hold.

As a result of this analysis, it has been seen that the plate which are AH and A grade do not exceed their strength limits (230 Mpa for A grades, 360 Mpa for AH grades).The stress values which occur on the plate because of the loading condition can be seen on related pictures in Appendix II, and the stress values, corresponding the point number declared in the Figure 2 of Appendix I, are summarized in Table 4.7. The shearing stress values were given as absolute values.

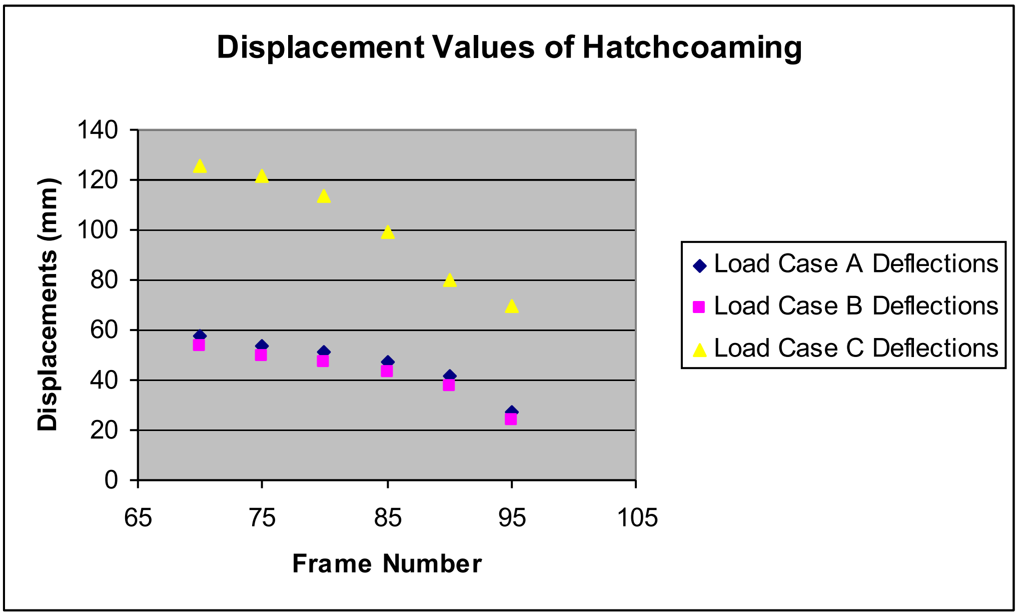

Figure 4.15 : Displacement values of hatchcoaming.

Table 4.7 : Stress summary.

Point		Load Cases		
		A	B	C
	Displacement	58,13 mm	54,91mm	122.41mm
1	Von Misses	162.95 N/mm^2	140.05 N/mm^2	102.05 N/mm^2
	Shear (XY)	22.52 N/mm^2	20.35 N/mm^2	17.8 n/N/mm^2
	Von Misses	282.45 N/mm^2	201.76 N/mm^2	204.65 N/mm^2
2	Shear (XZ)	26.53 N/mm^2	19.62 N/mm^2	18.9 N/mm^2
	Von Misses	197.86 N/mm^2	150.02 N/mm^2	153.09 N/mm^2
3	Shear (YZ)	79.882 N/mm^2	73.296 N/mm^2	125.22 N/mm^2
	Von Misses	175.15 N/mm^2	200.54 N/mm^2	221.20 N/mm^2
4	Shear (XY)	68.51 N/mm^2	71.44 N/mm^2	70.75 N/mm^2
	Von Misses	113.87 N/mm^2	152.27 N/mm^2	122.42 N/mm^2
5	Shear (XZ)	80.01 N/mm^2	92.02 N/mm^2	116.28 N/mm^2

5. CONCLUSION AND RECOMMENDATIONS

In this work, it is aimed to create a procedure to the structural analyses by means of direct strength assessment for ship less than 170 m in length. Unfortunately there is no class procedure of direct strength assessment for ship less than 170 m in length.

The ship we analyzed is less than 170m and it has two cargo hold .Basically almost all class society offer three cargo hold model. For these reasons it is impossible to apply class rules to this ship for direct strength assessment.

Moreover, we developed a different procedure which is a combination of these two methods and this method was applied to this ship as well. Method is that, we create two cargo hold of the ship as well as finely meshing middle part and (half of the cargo hold one, bulkhead, and half of the cargo hold two) and coarsely meshing the other part.

As I mentioned above, this is just start of a work. My main aim is to develop an analyses procedure to small ships.

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APPENDICES

APPENDIX A:

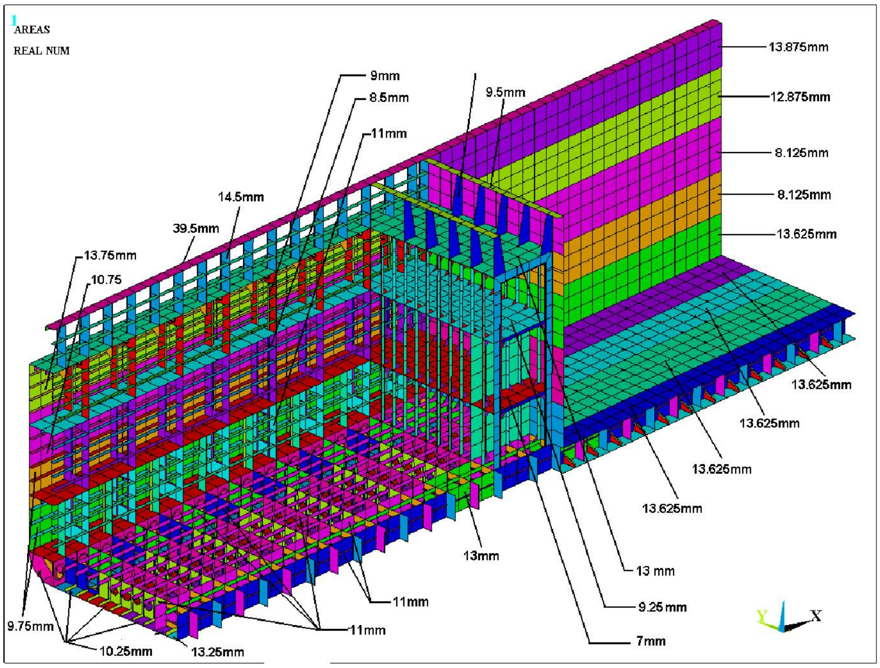

Figure A.1 : Shell thickness.

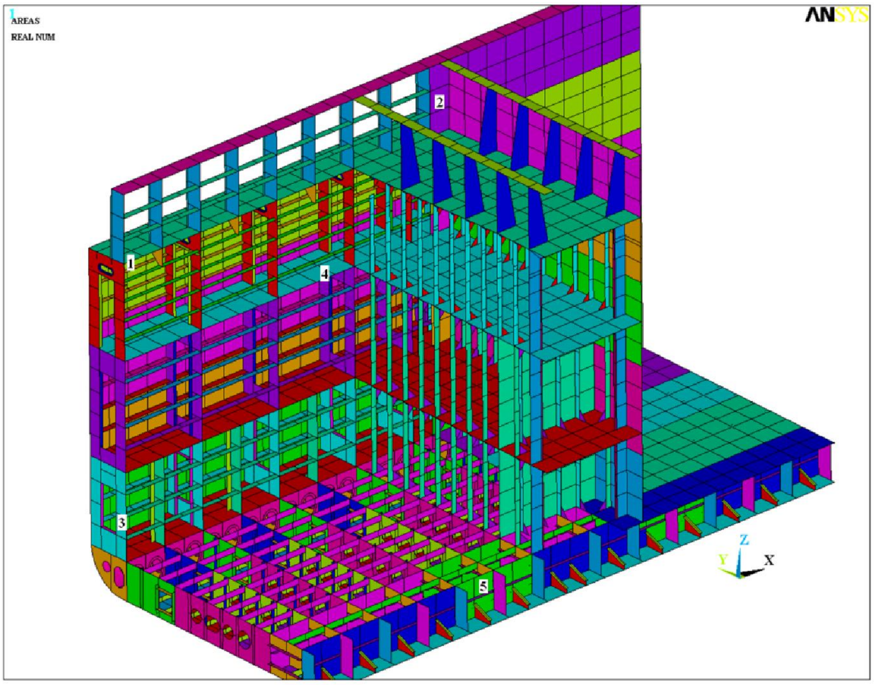

Figure A.2 : Stress points.

APPENDIX B

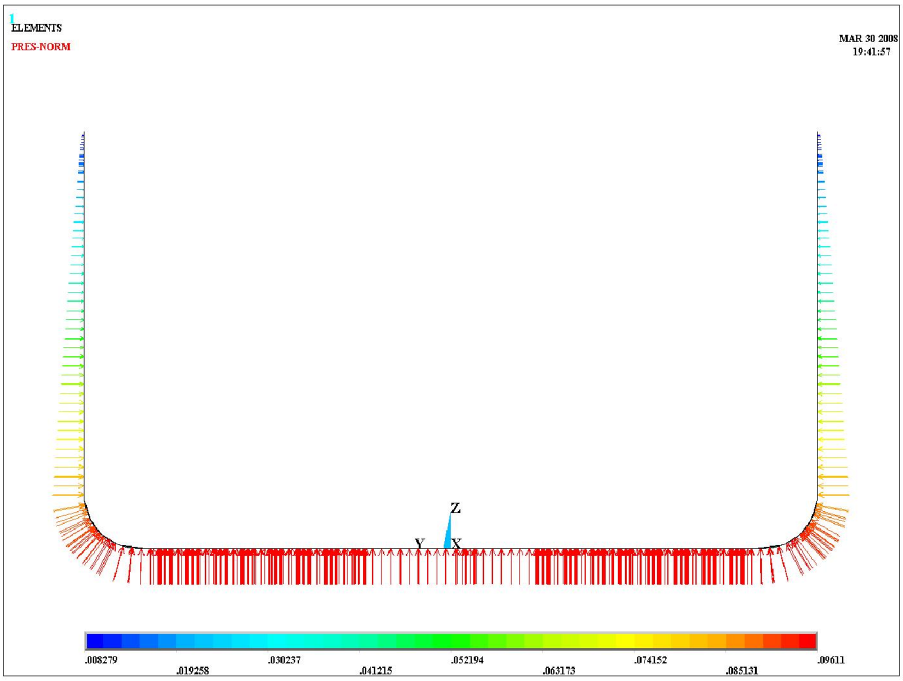

Figure B.1 : Sea pressure loading values of load case A (N/mm^2).

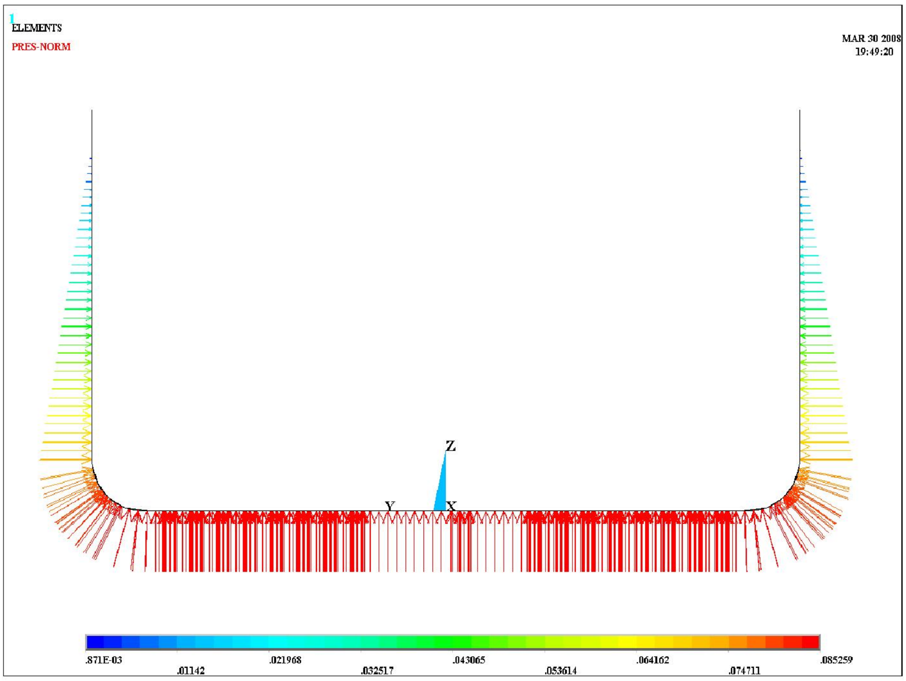

Figure B.2 : Sea pressure loading values of load case B (N/mm^2).

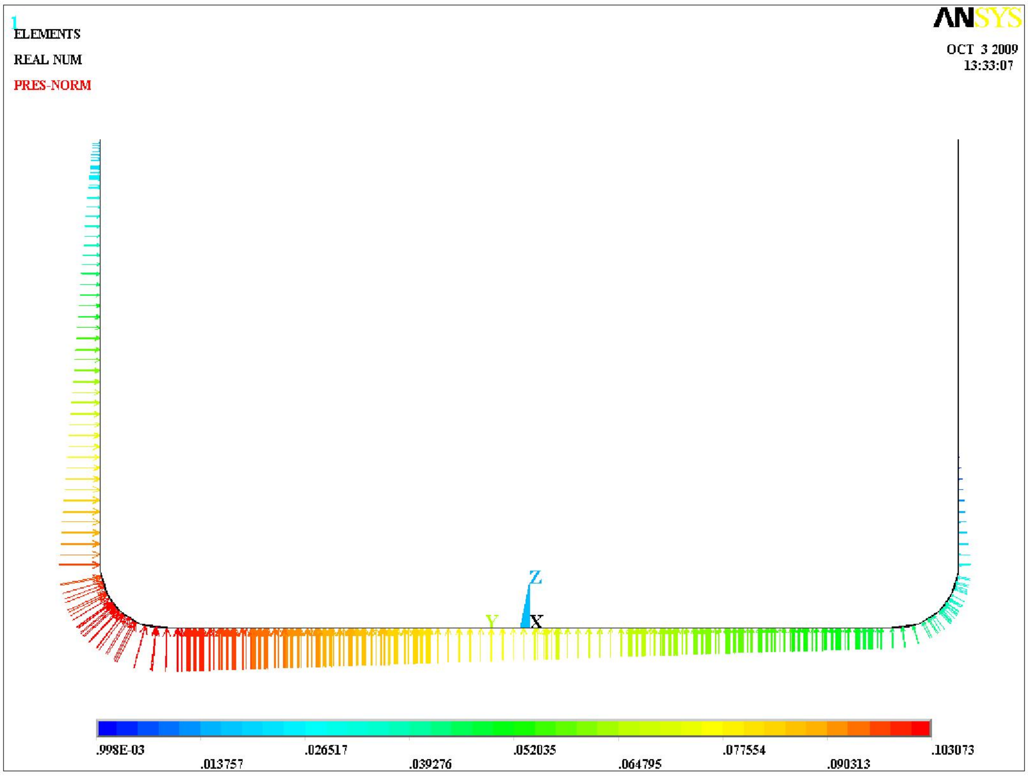

Figure B.3 : Sea pressure loading values of load case C (N/mm^2).

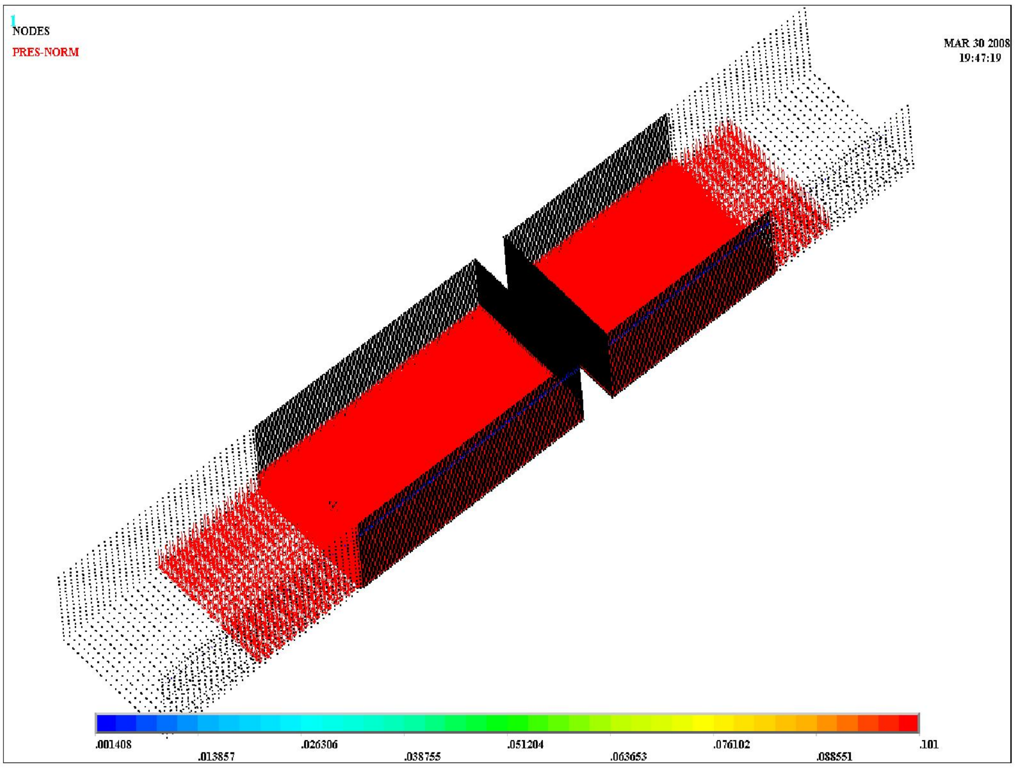

Figure B.4 : Internal pressure loading values of load case A (N/mm^2).

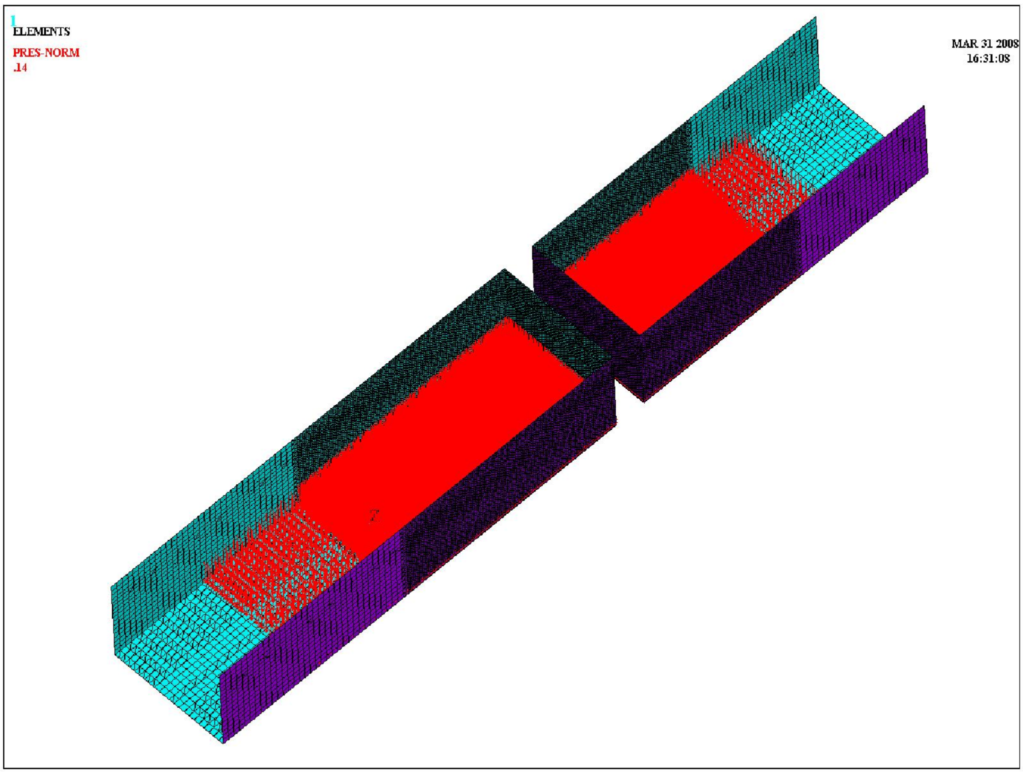

Figure B.5 : Internal pressure loading values of load case B (N/mm^2).

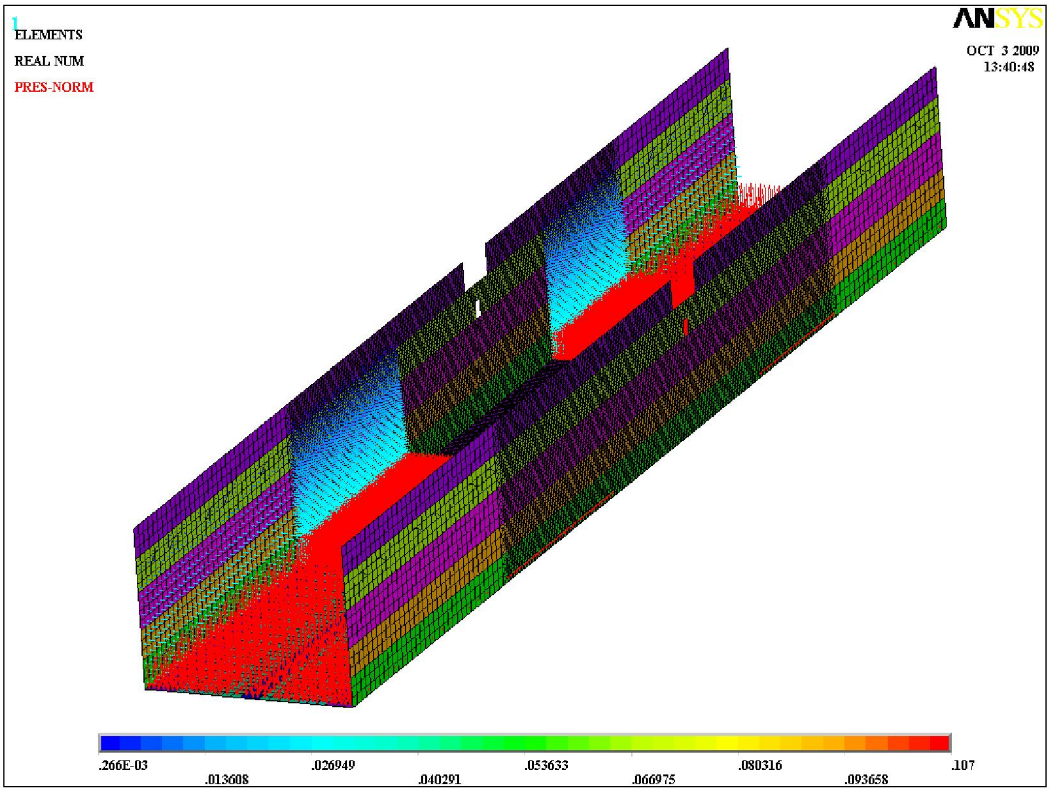

Figure B.6 : Internal pressure loading values of load case C (N/mm^2).

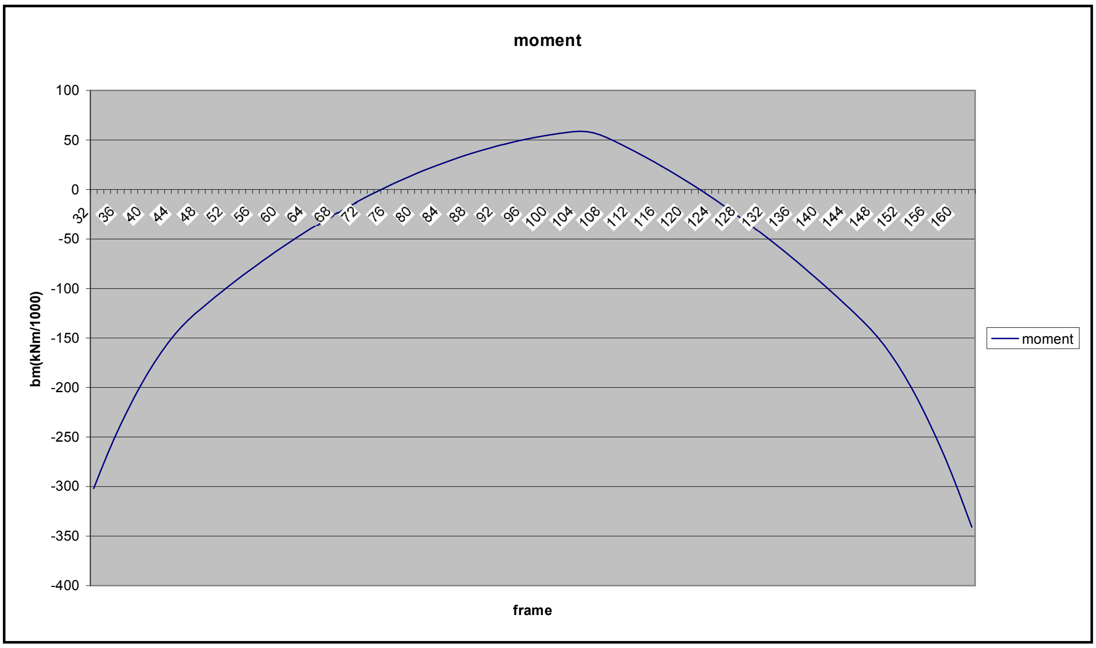

Figure B.7 : Vertical bending moment distribution along the model at loading condition A.

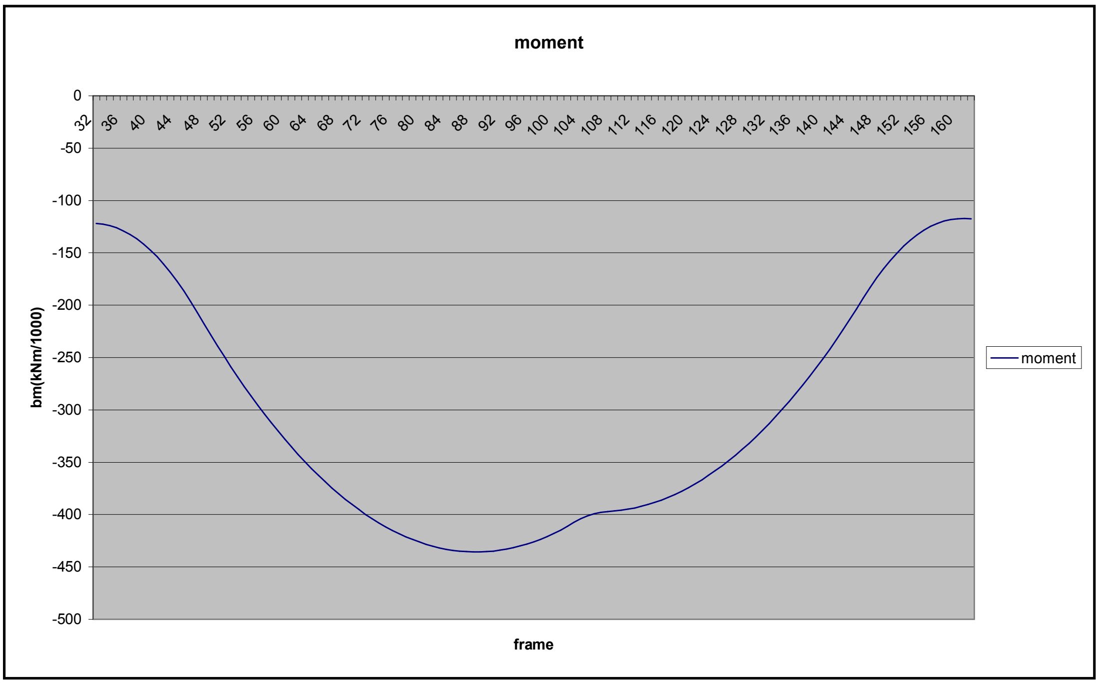

Figure B.8 : Vertical bending moment distribution along the model at loading condition B.

APPENDIX C

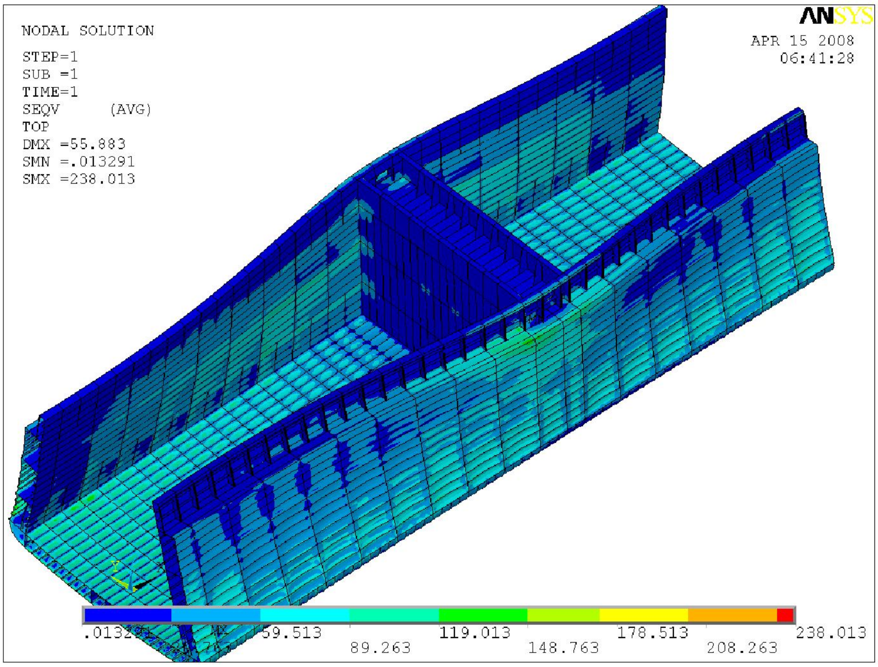

Figure C.1 : Von misses stress result at load case A (MPa).

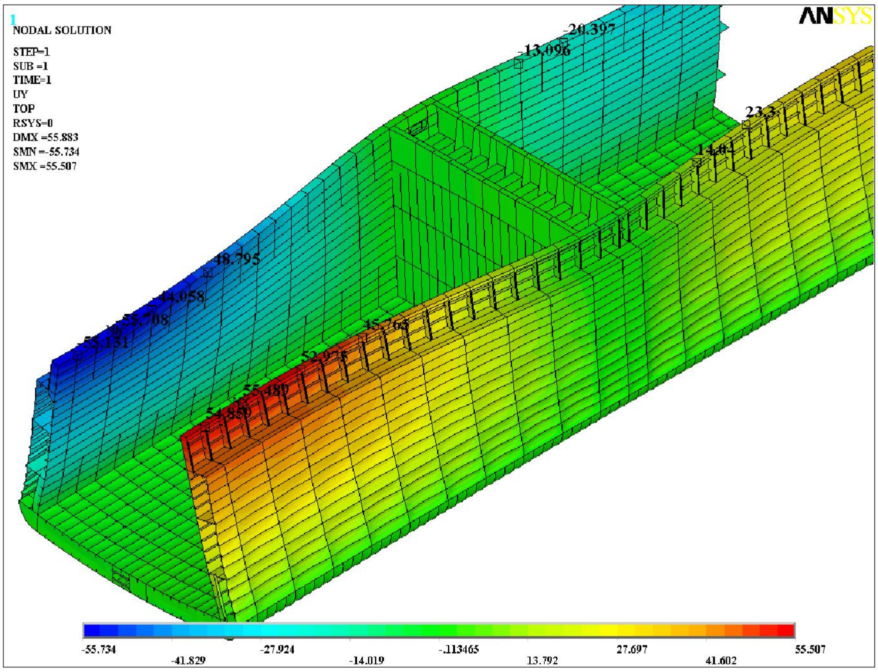

Figure C.2 : Y direction displacement at load case A (mm).

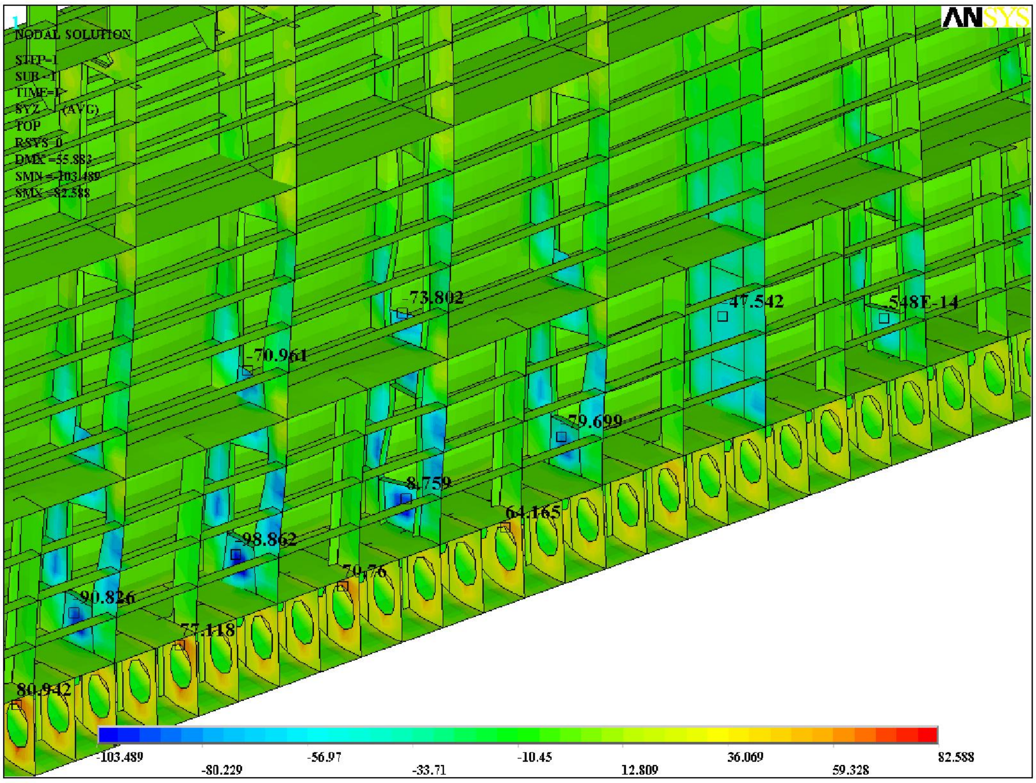

Figure C.3 : YZ direction share stress result at side girders at load case A (MPa).

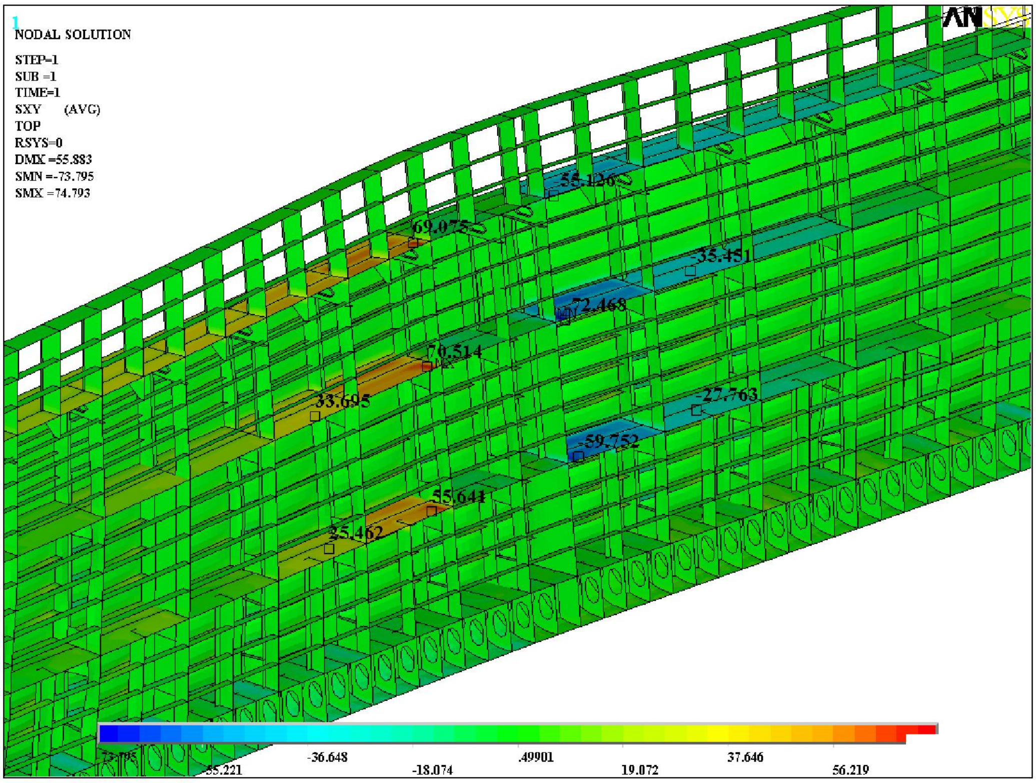

Figure C.4 : XY direction share stress result at side girders at load case A (MPa).

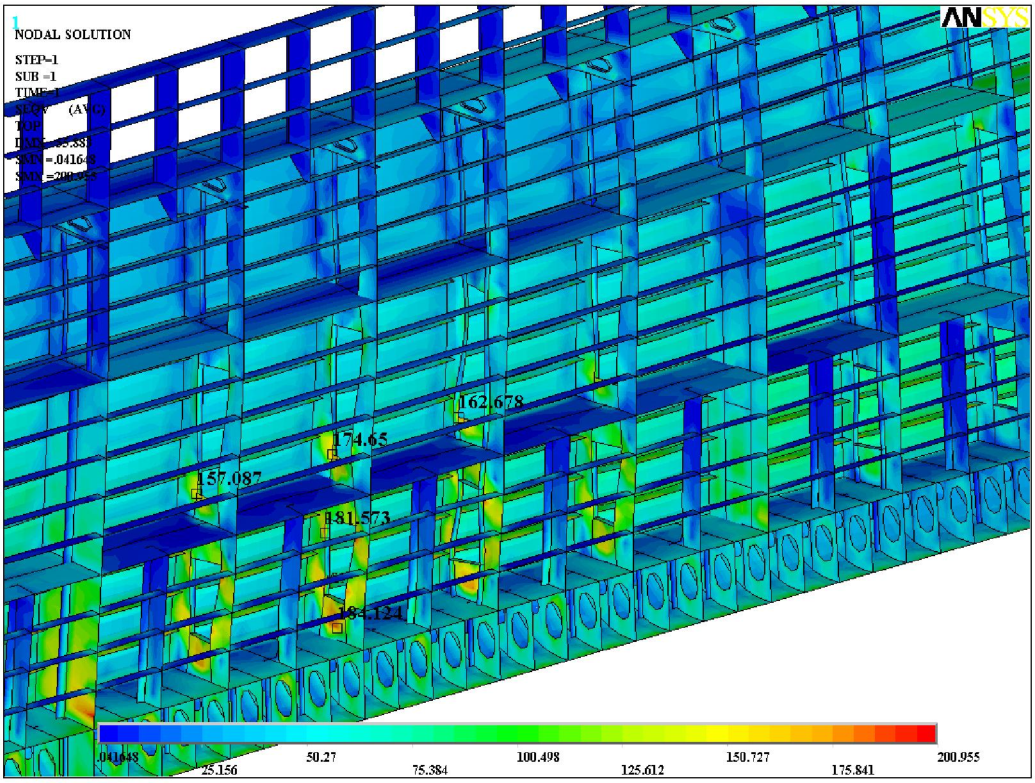

Figure C.5 : Von misses stress result at side girders at load case A (MPa).

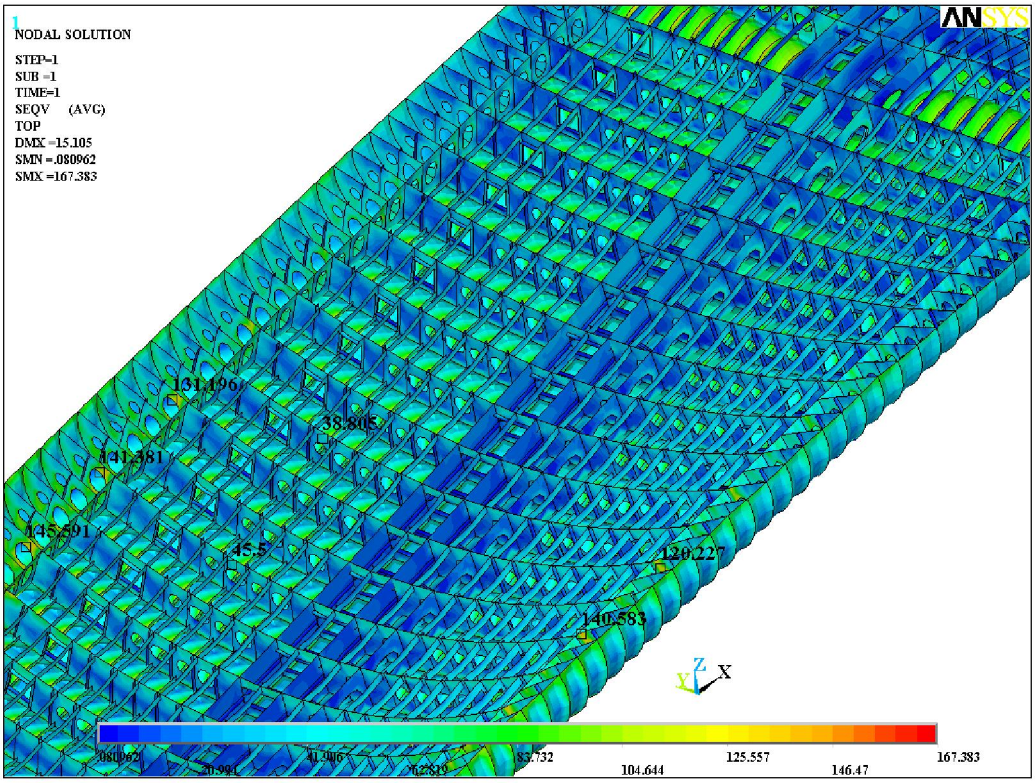

Figure C.6 : Von misses stress result at double bottom at load case A (MPa).

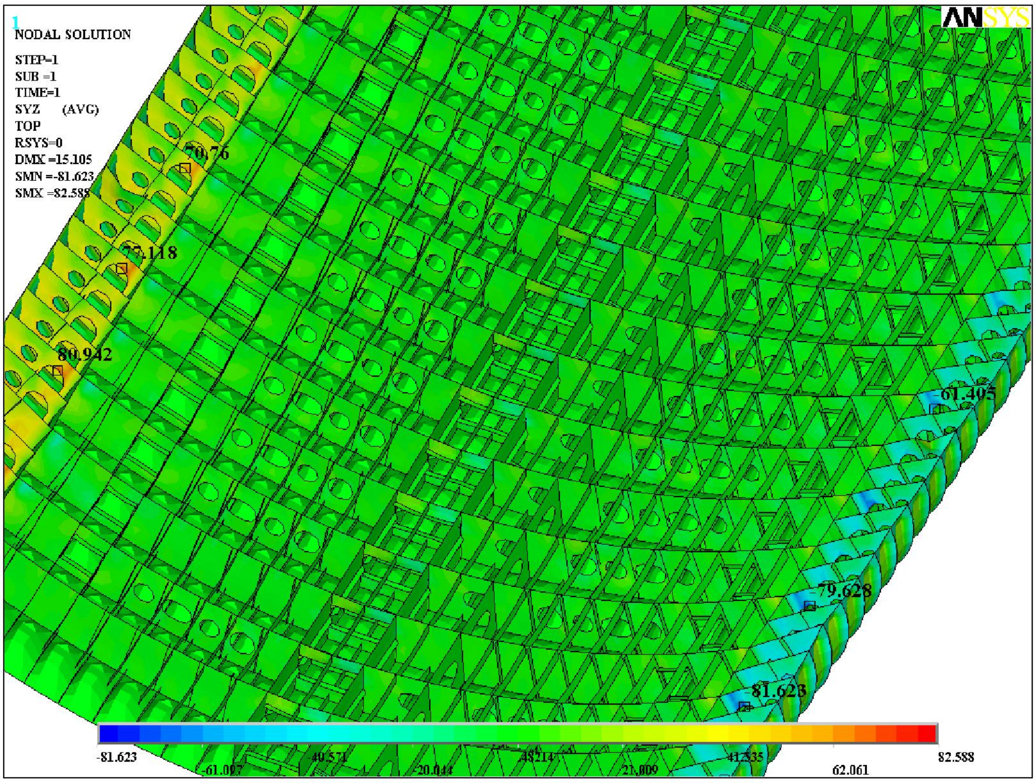

Figure C.7 : YZ direction share stress result at double bottom at load case A (MPa).

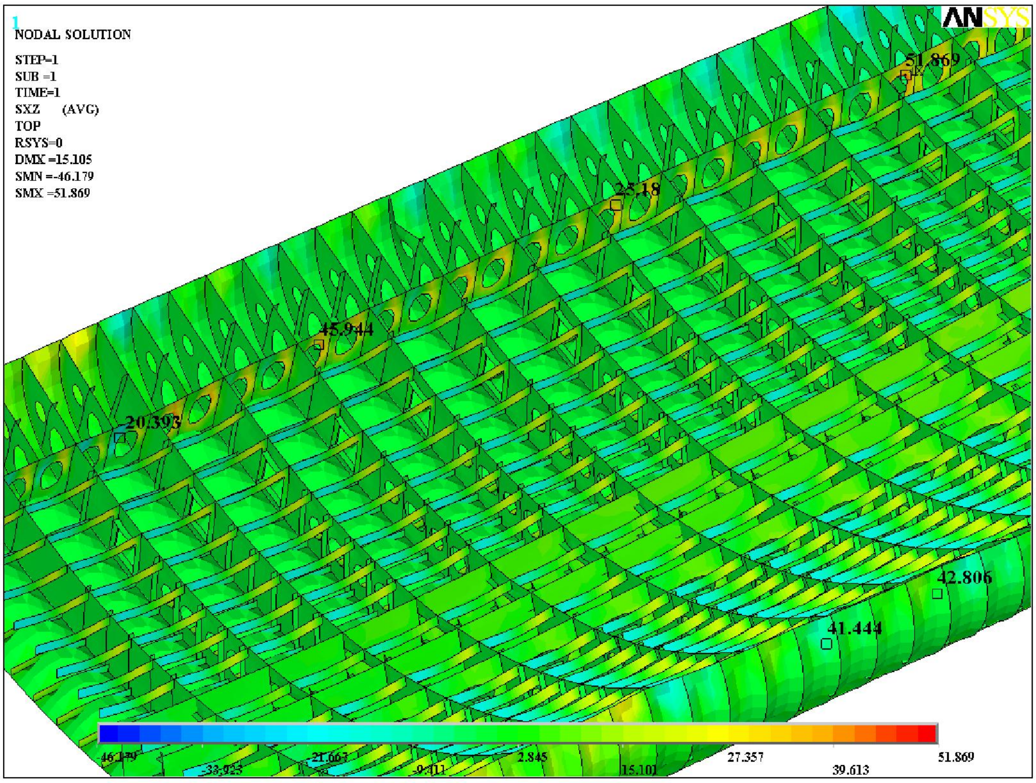

Figure C.8 : XZ direction share stress result at side girders at load case A (MPa).

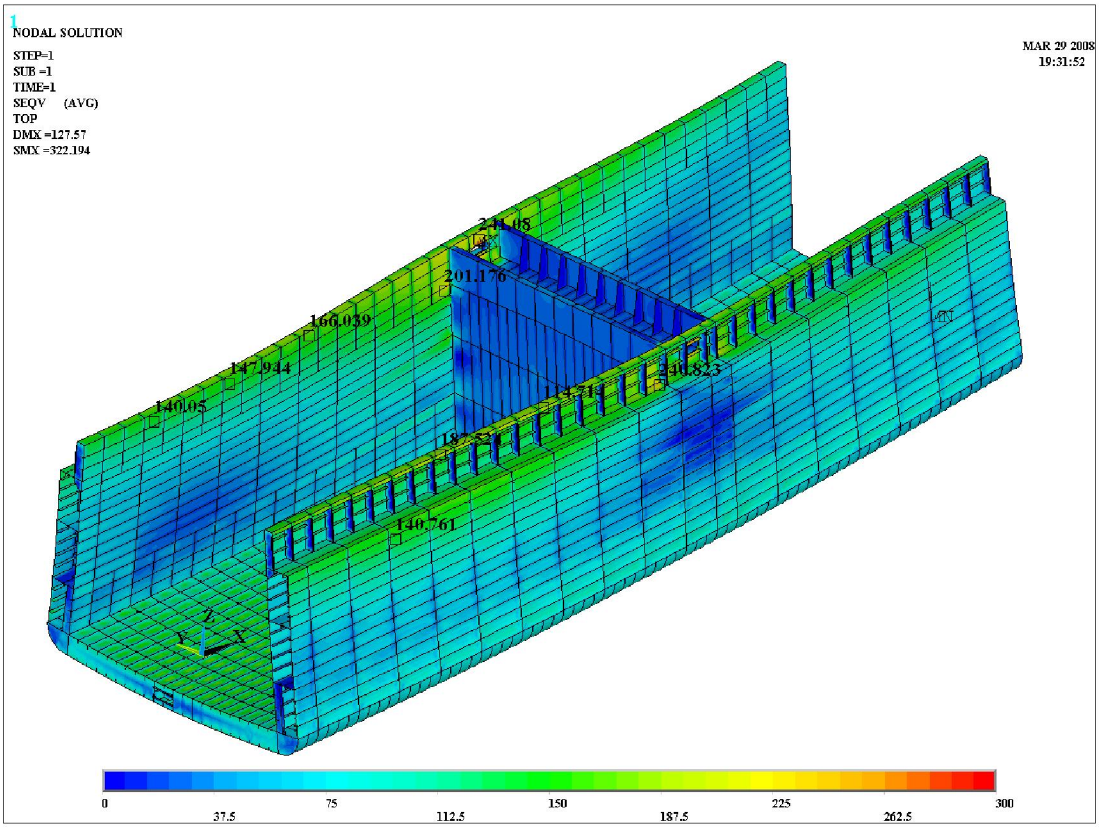

Figure C.9 : Von misses stress result at load case B (MPa).

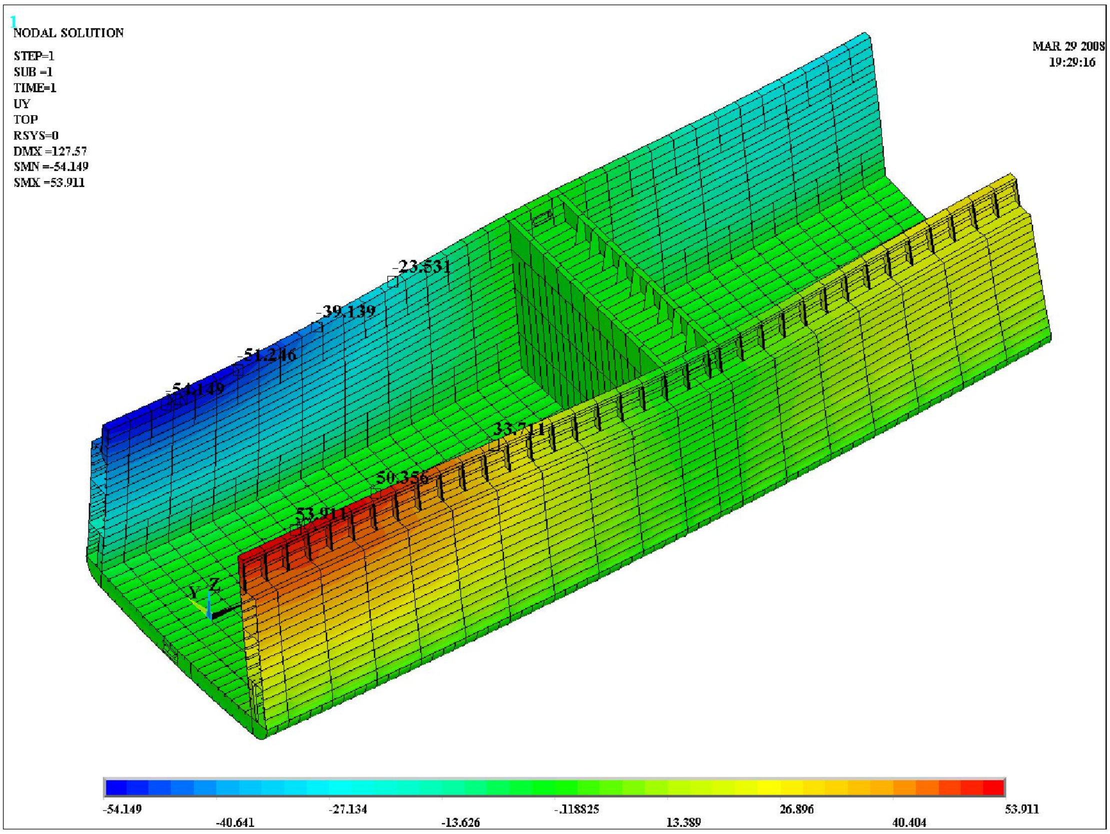

Figure C.10 : Y direction displacement at load case B (mm).

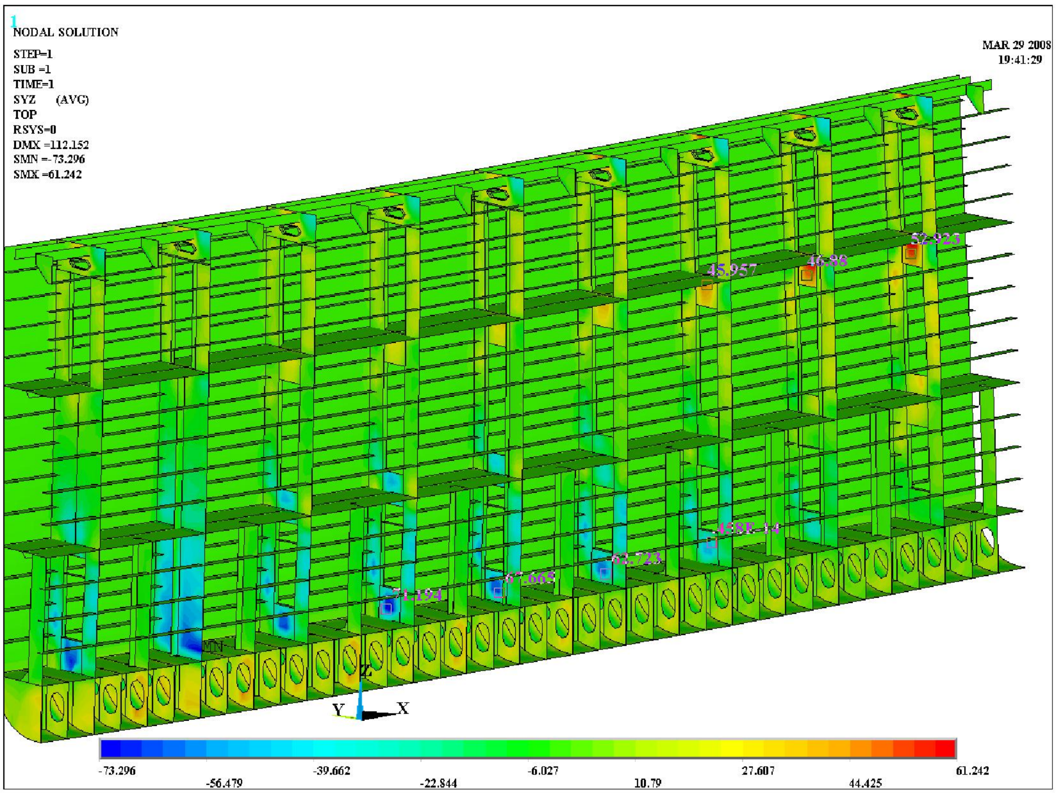

Figure C.11 : YZ direction share stress result at side girders at load case B (MPa).

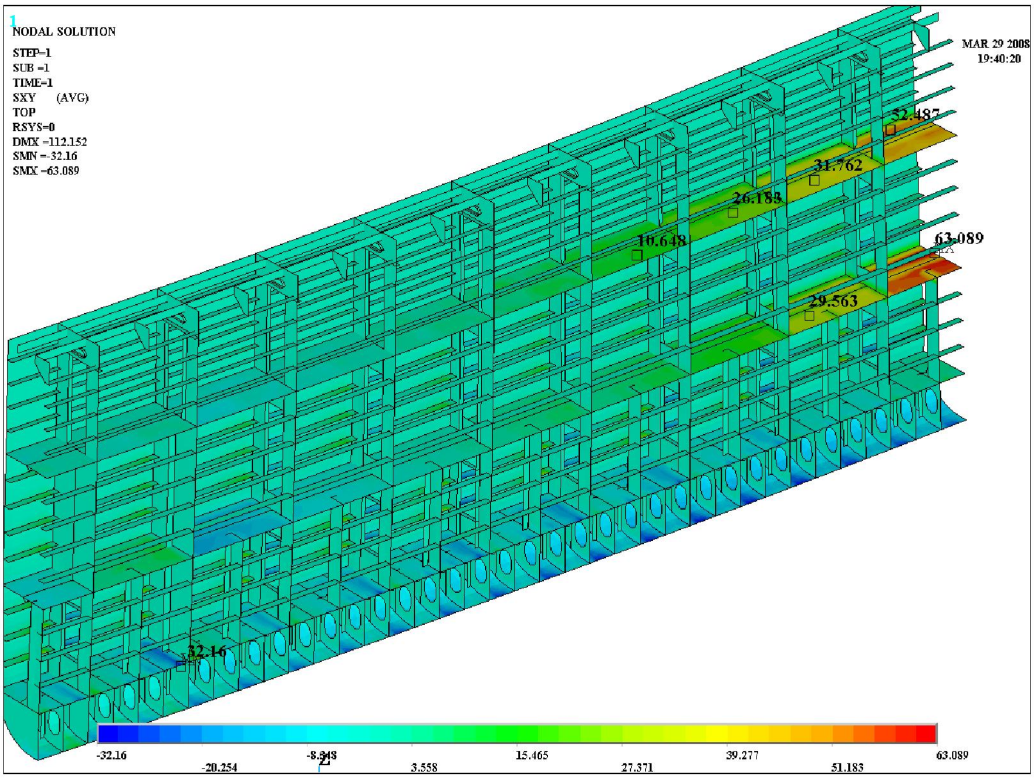

Figure C.12 : XY direction share stress result at side girders at load case B (MPa).

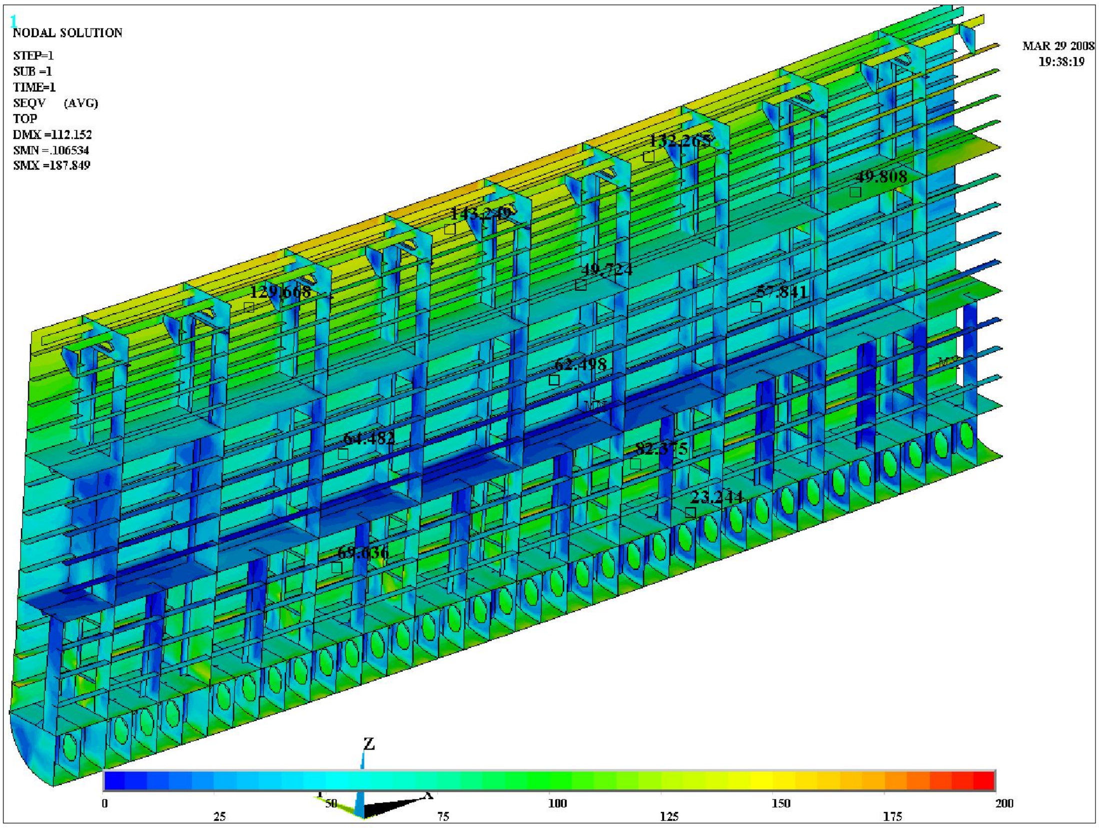

Figure C.13 : Von misses stress result at side girders at load case B (MPa).

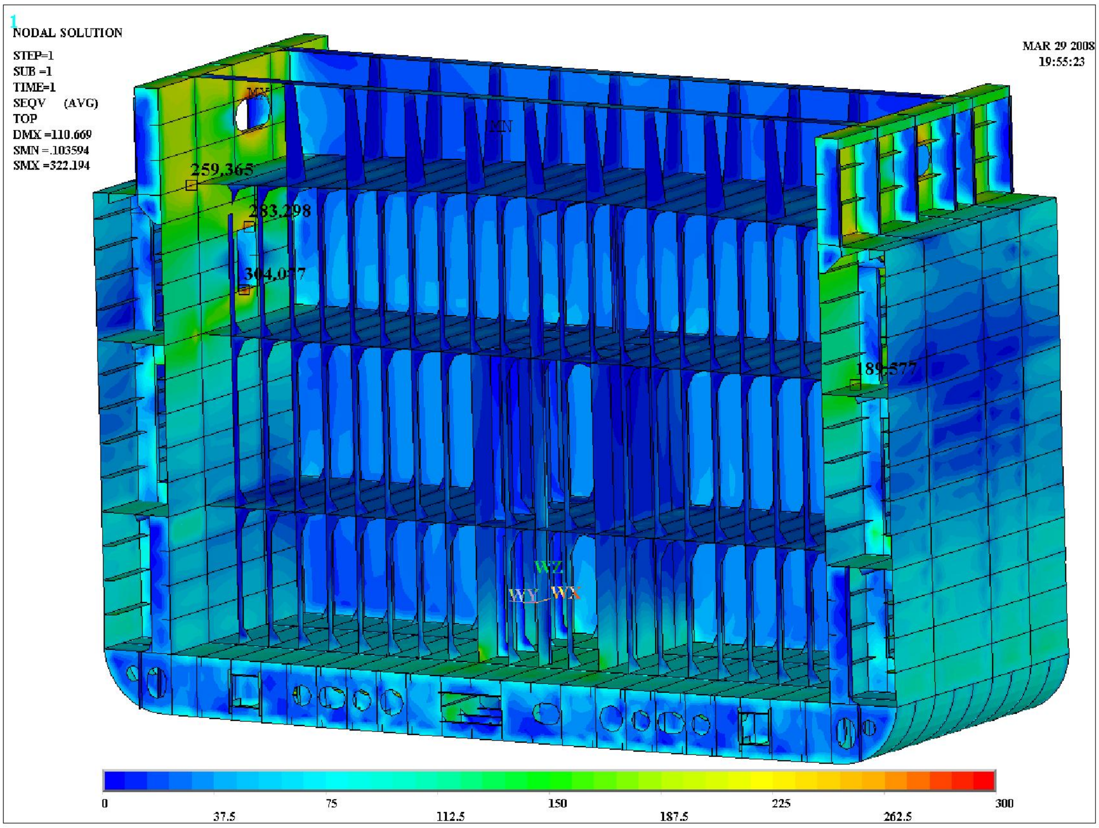

Figure C.14 : Von misses stress result at load case A (MPa).

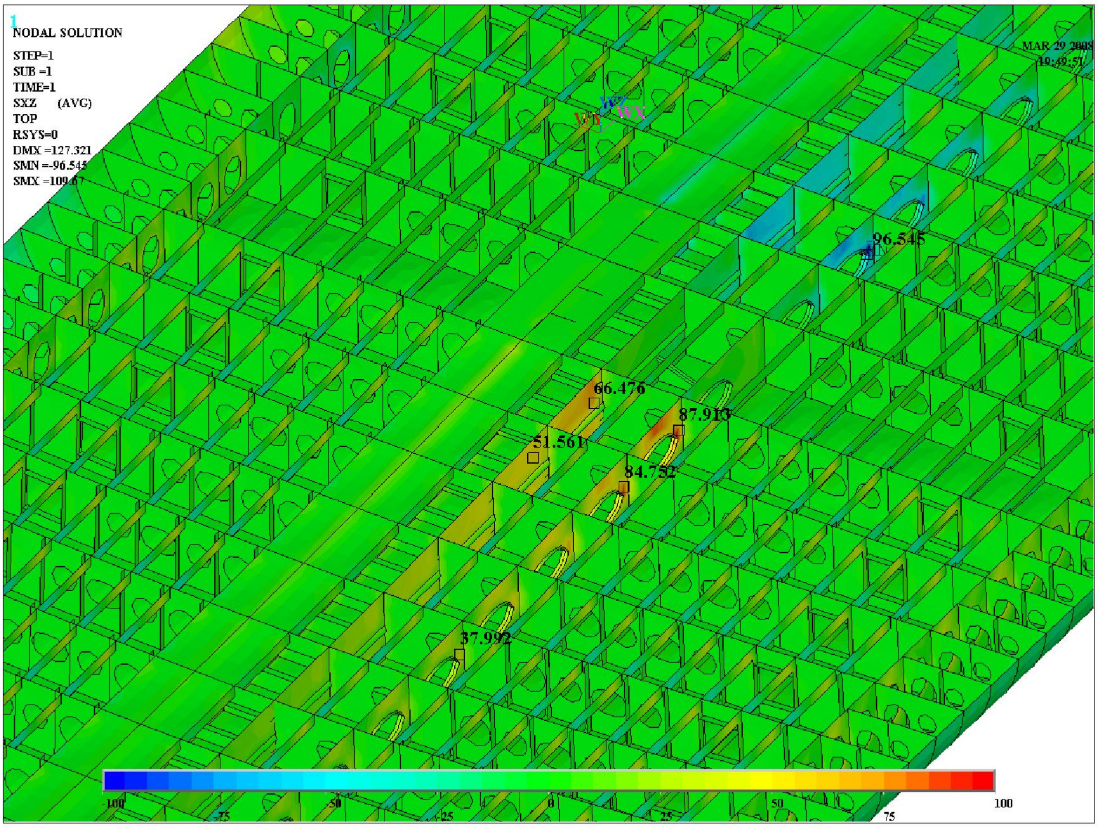

Figure C.15 : YZ direction share stress result at double bottom at load case B (MPa).

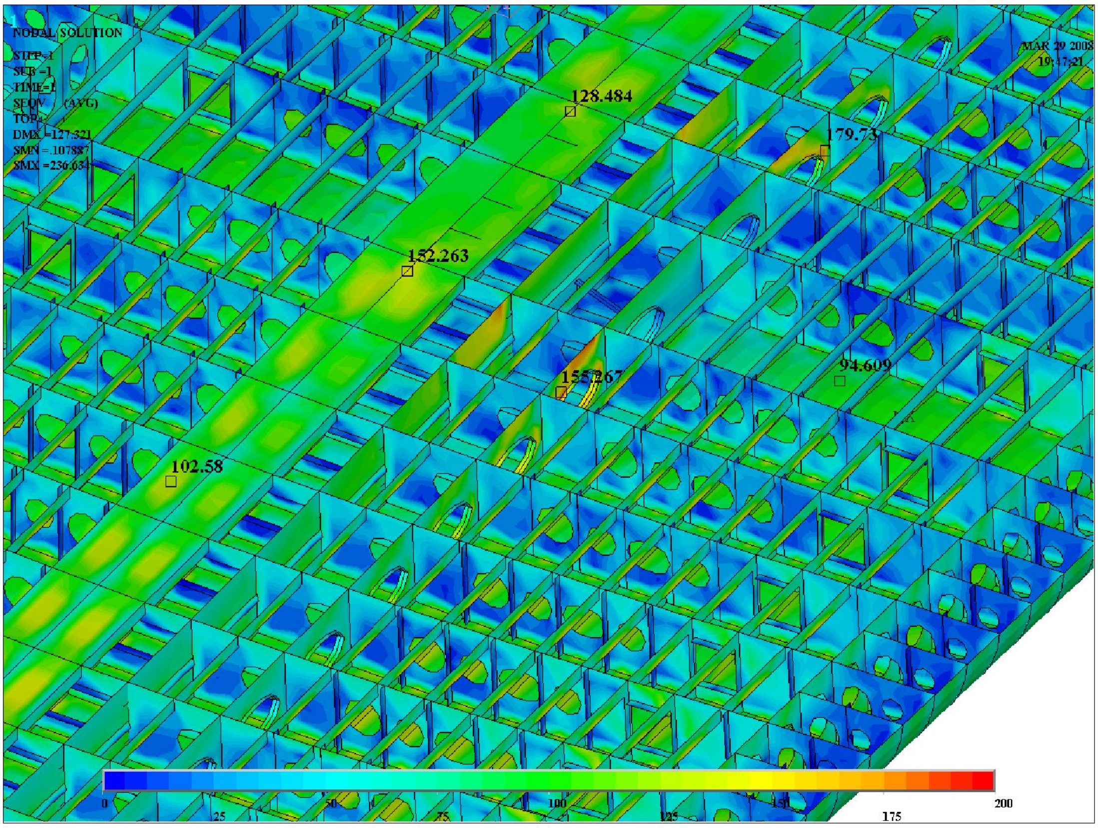

Figure C.16 : Von misses stress result at double bottom at load case B (MPa).

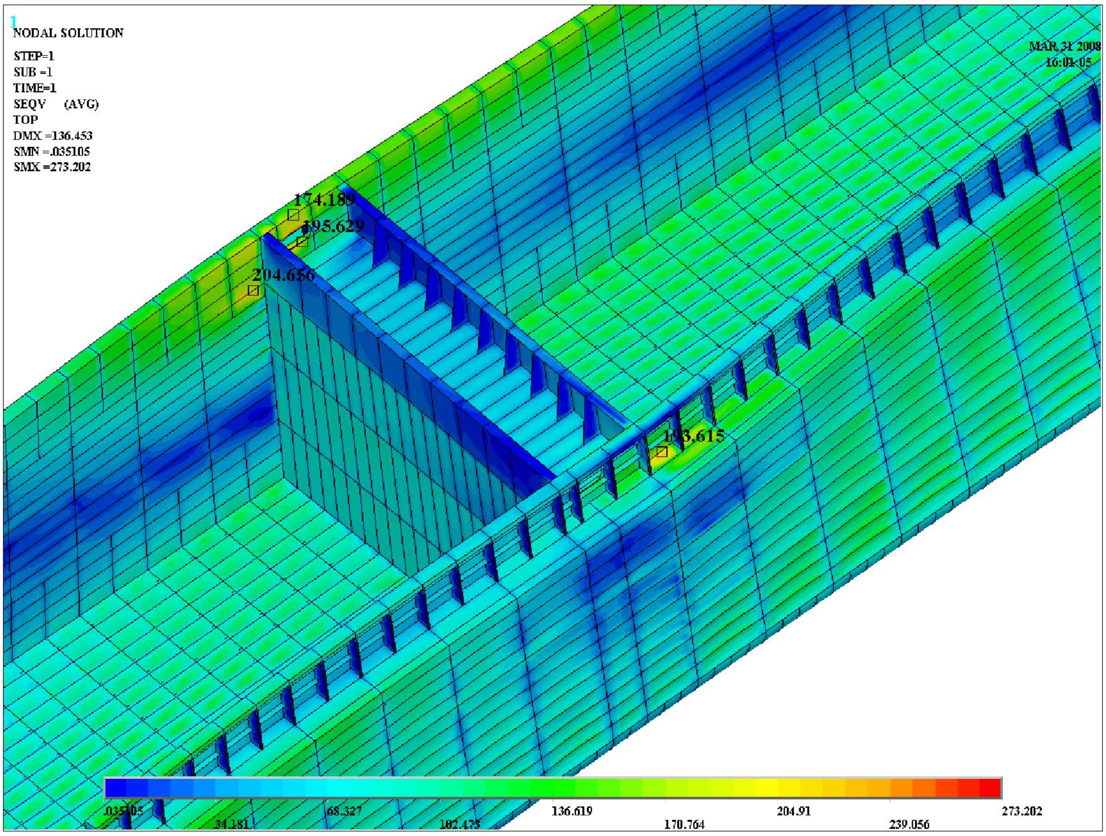

Figure C.17 : Von misses stress result at load case C (MPa).

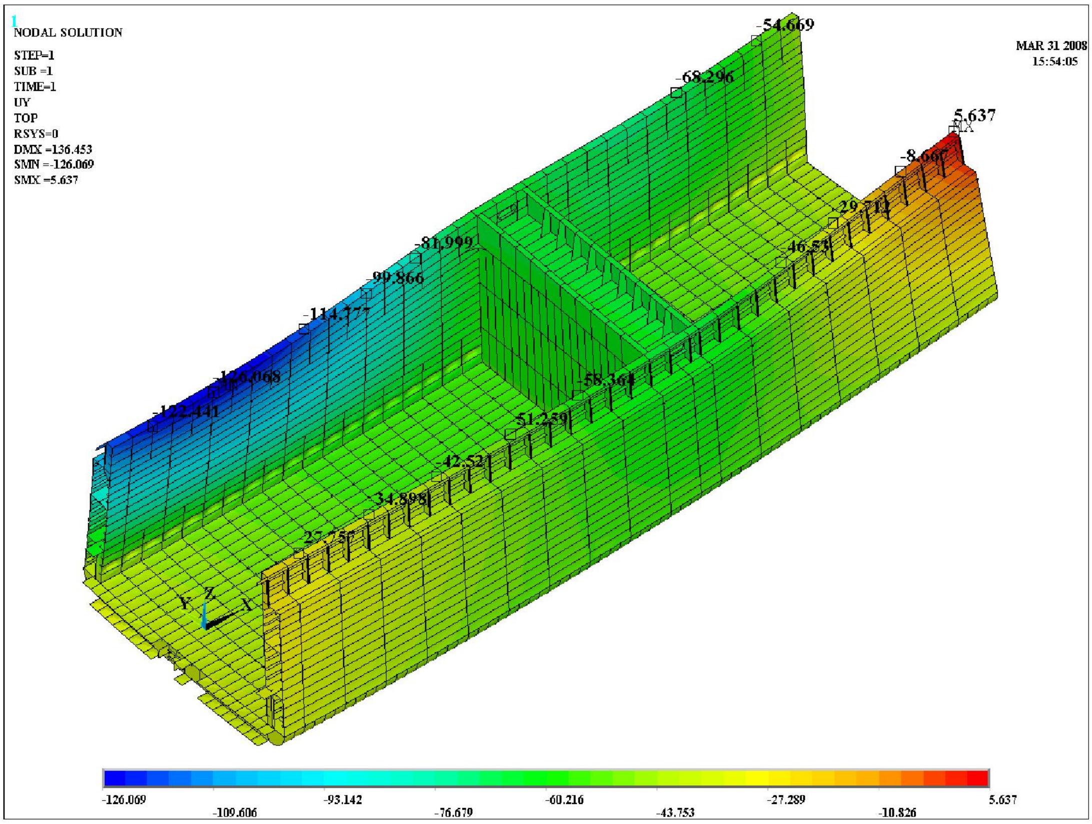

Figure C.18 : Y direction displacement at load case C (mm).

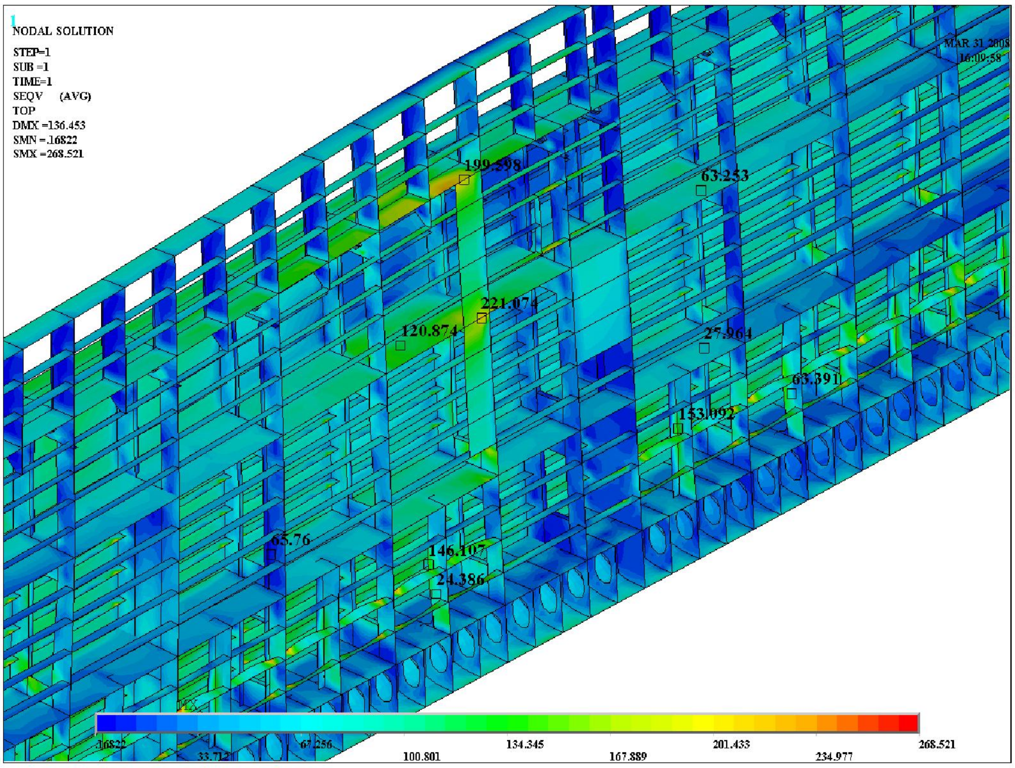

Figure C.19 : Von misses stress result at side girders at load case C (MPa).

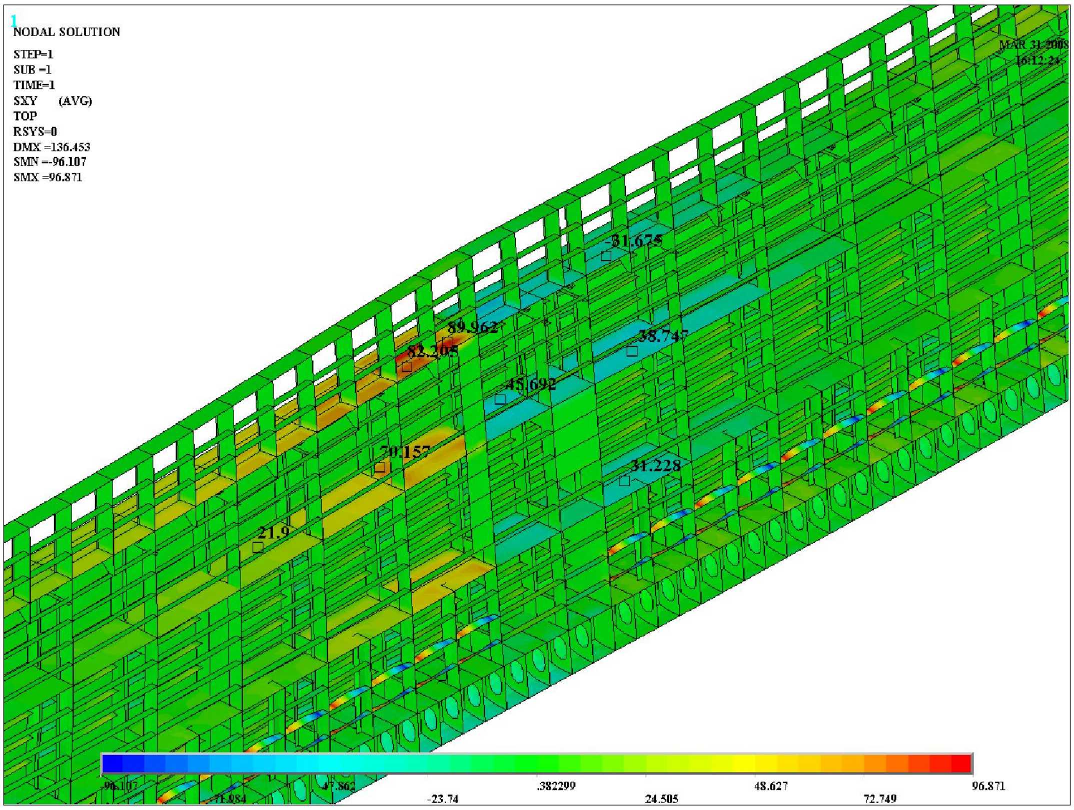

Figure C.20 : XY direction share stress result at side girders at load case C (MPa).

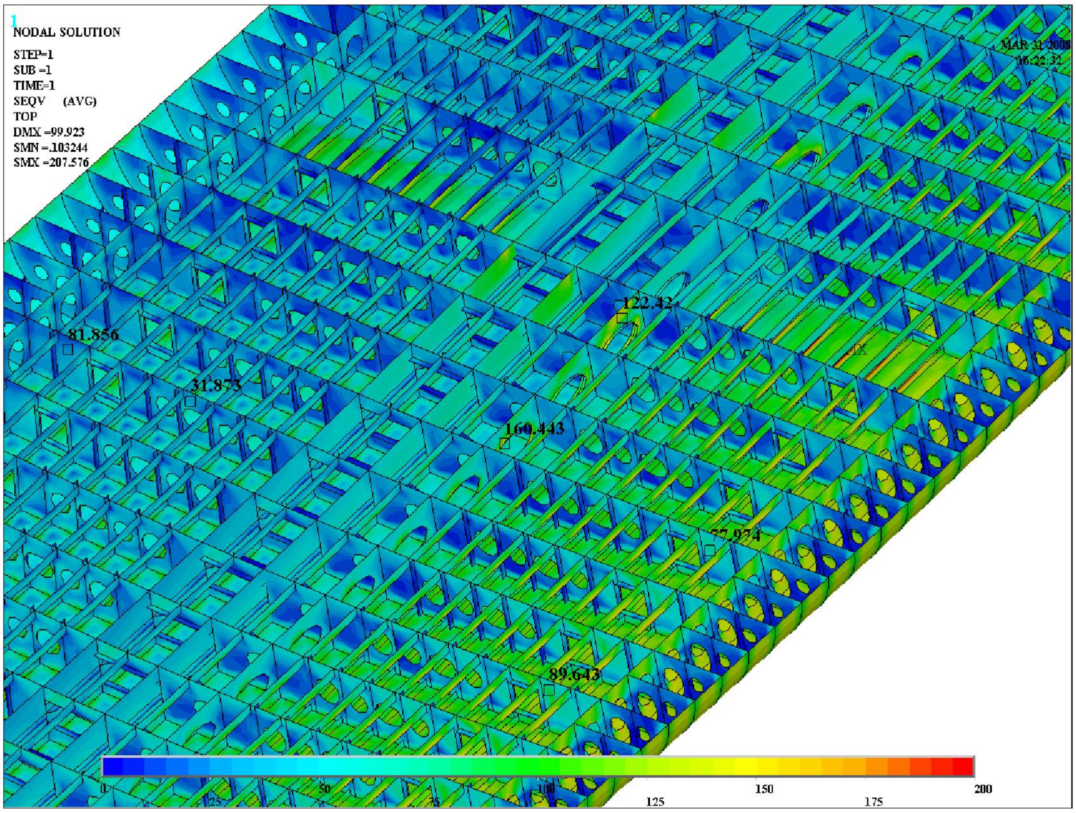

Figure C.21 : Von misses stress result at double bottom at load case C (MPa).

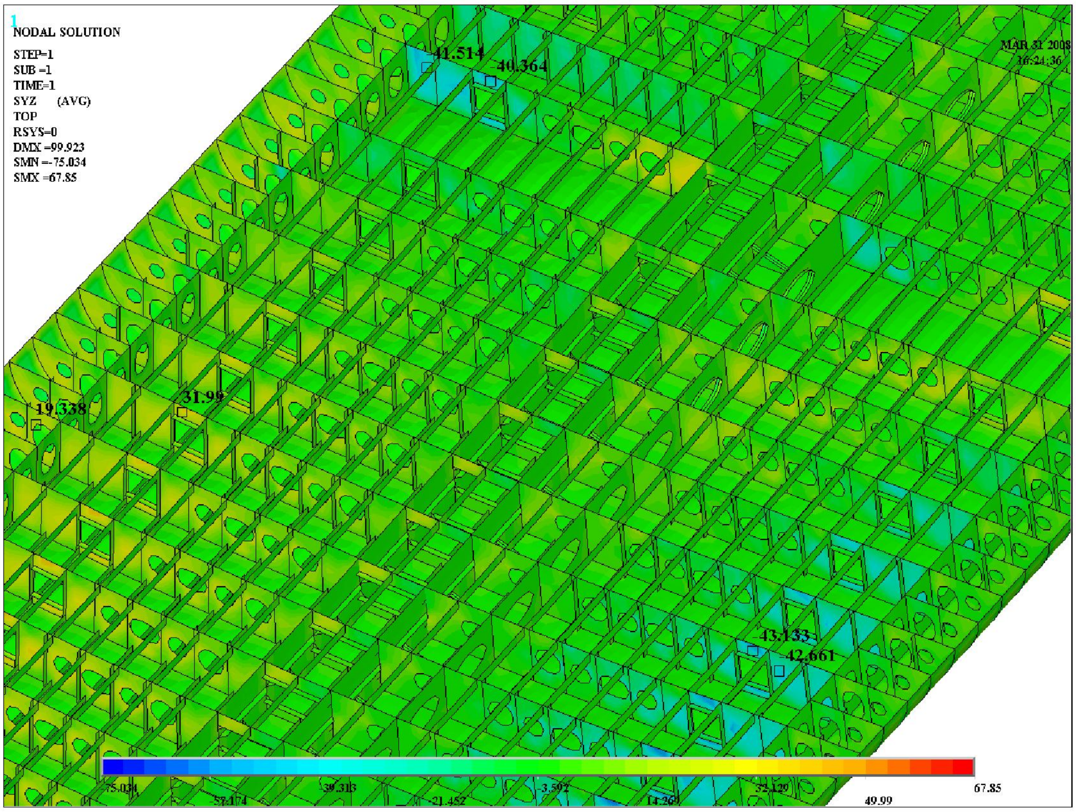

Figure C.22 : XY direction share stress result at side girders at load case C (MPa).

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